AD-A092 449   DAVID W TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CE--ETC   F/G 13/10
PREDICTION OF THRUST-DEDUCTION AND WAKE FRACTIONS FOR TWIN-SCRE--ETC(U)
NOV 80   R B HURWITZ
UNCLASSIFIED   DTNSRDC/SPD-693-02   NL

1 OF 2
AD
A092449

LEVEL II

DAVID W. TAYLOR NAVAL SHIP
RESEARCH AND DEVELOPMENT CENTER
Bethesda, Maryland 20084

PREDICTION OF THRUST-DEDUCTION AND WAKE FRACTIONS FOR TWIN-SCREW DESTROYERS

by

RAE B. HURWITZ

APPROVED FOR PUBLIC RELEASE: Distribution Unlimited

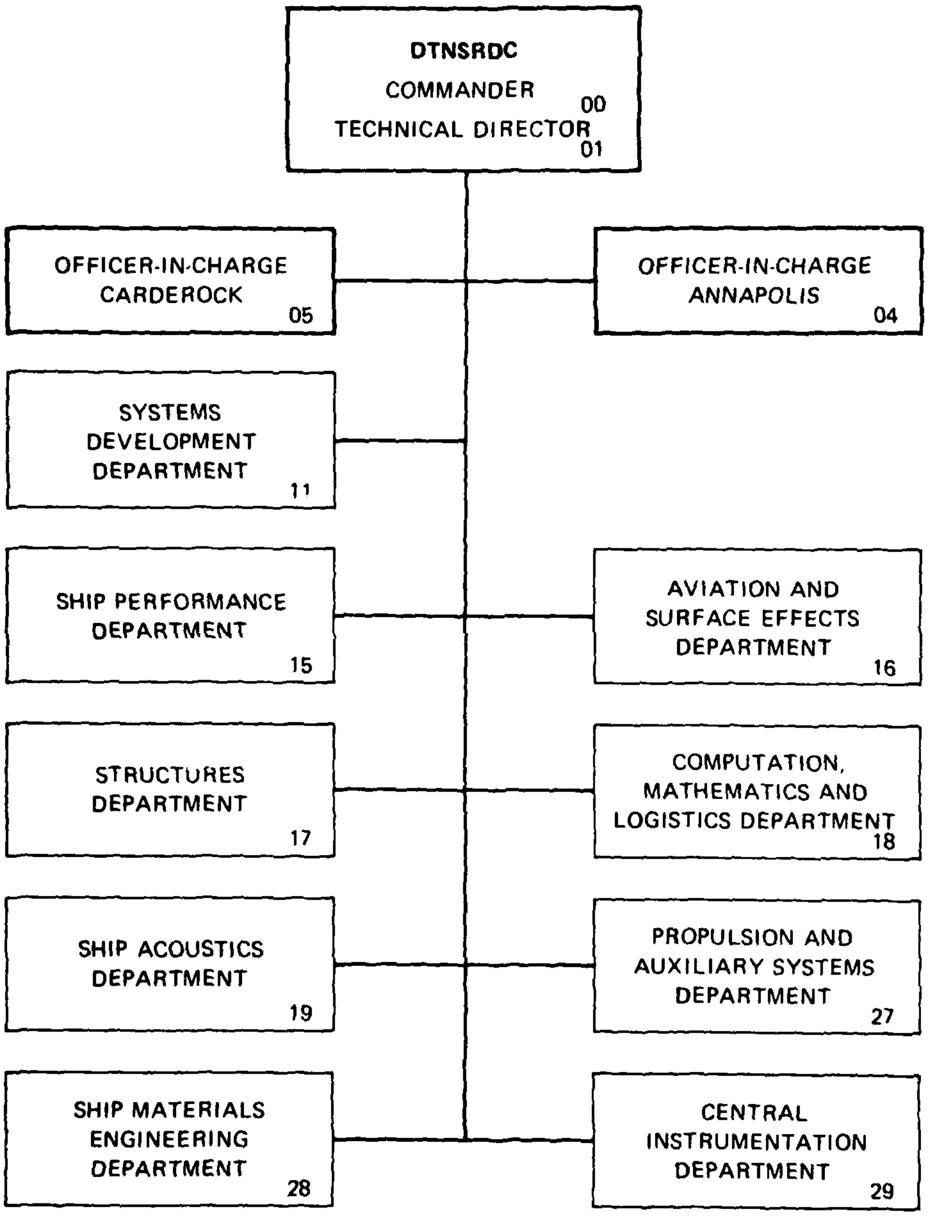
Ship Performance Department

NOVEMBER 1980

DTNSRDC/SPD-693-02

PREDICTION OF THRUST-DEDUCTION AND WAKE FRACTIONS FOR TWIN-SCREW
DESTROYERS

MAJOR DTNSRDC ORGANIZATIONAL COMPONENTS



REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: DTNSRDC/SPD-693-02	2. GOVT ACCESSION NO.: AD-A092
3. RECIPIENT'S CATALOG NUMBER: 449	
4. TITLE (and Subtitle): PREDICTION OF THRUST-DEDUCTION AND WAKE FRACTIONS FOR TWIN-SCREW DESTROYERS	5. TYPE OF REPORT & PERIOD COVERED: FINAL
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): RAE B. HURWITZ	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: David W. Taylor Naval Ship R&D Center, Ship Performance Department, Bethesda, MD 20084	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: Program Element 62543N, Task Element ZF-43-421-001
11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Material Command, Washington, DC 20362	12. REPORT DATE: November 1980
	13. NUMBER OF PAGES: 105 + xii
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Thrust-deduction fraction
Thrust-wake fraction

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This work describes the development of a technique for predicting the propulsion coefficients from hull-form parameters. The two propulsive coefficients used at DTNSRDC and included in this study are the thrust-deduction fraction (t) and the thrust-wake fraction (w_T). A prediction method has been derived from data of sixty-five experiments on model hulls representing a variety of twin-screw destroyers. Examples show that the prediction models provide fair results within the range of data represented. Additional work is recommended to develop an improved prediction method.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (CONTINUED)

LIST OF FIGURES (CONTINUED)

LIST OF TABLES

LIST OF TABLES (CONTINUED)

NOTATION

A_{BT}	Sectional area at forward perpendicular
A_M	Sectional area at midships
A_0	Disk area
A_P	Projected blade area
A_P/A_0	Projected area-disk area ratio
A_{WA}	Afterbody waterplane area
A_{WF}	Forebody waterplane area
A_W	Total area of waterplane
A_X	Area of maximum transverse section
B	Beam or breadth, molded of a ship
B_X	Beam at the waterline at maximum transverse section
B_X/T_X	Beam-draft ratio
C_P	Longitudinal prismatic coefficient
C_{PA}	Afterbody prismatic coefficient
C_{PE}	Entrance prismatic coefficient
C_{PF}	Forebody prismatic coefficient
C_{PR}	Run prismatic coefficient
C_{WP}	Waterplane coefficient
C_{WPA}	Afterbody waterplane coefficient
C_{WPF}	Forebody waterplane coefficient

NOTATION (CONTINUED)

D	Diameter of a propeller
D/T	Propeller diameter-draft ratio
$\overline{FB}$	Distance of longitudinal center of buoyancy from forward perpendicular
$\overline{FF}$	Distance of longitudinal center of flotation from forward perpendicular
f_{B_T}	Area ratio at bow; Taylor's "f" at forward perpendicular
g	Gravitational constant
i_E	Half angle of entrance
J_T	Advance coefficient
J_V	Ship speed advance coefficient
K_T	Thrust coefficient
L or L_{WL}	Total length on waterline
L_A	Length of afterbody
L_E	Length of entrance
L_F	Length of forebody
L_P	Length of parallel middlebody
L_R	Length of run
L_{WL}/B_X	Length-beam ratio
P	Propeller pitch
P/D	Pitch ratio
R	Resistance

NOTATION (CONTINUED)

R_n	Reynolds number based on ship length
S	Wetted surface
Ⓢ	Froude's wetted surface coefficient
T	Draft, molded of a ship
TH	Thrust at propeller
T_X	Draft at maximum transverse section
t	Thrust-deduction fraction
V	Speed of ship
$V/\sqrt{gL_{WL}}$	Froude number
w_T	Taylor wake fraction determined from thrust
Δ	Displacement weight
λ	Scale ratio, lambda
∇ or ∇_T	Total displaced volume
$\nabla/(0.10L)^3$	Fatness Ratio
∇_A	Volume of afterbody
∇_E	Volume of entrance
∇_F	Volume of forebody
∇_R	Volume of run
ν	Kinematic Viscosity

ABSTRACT

This work describes the development of a technique for predicting the propulsion coefficients from hull-form parameters. The two propulsive coefficients used at DTNSRDC and included in this study are the thrust-deduction fraction (t) and the thrust-wake fraction (w_T). A prediction method has been derived from data of sixty-five experiments on model hulls representing a variety of twin-screw destroyers. Examples show that the prediction models provide fair results within the range of data represented. Additional work is recommended to develop an improved prediction method.

ADMINISTRATIVE INFORMATION

The David Taylor Naval Ship R&D Center (DTNSRDC) was requested under the Ship Performance and Hydromechanics Program, sponsored by the Naval Material Command (NAVMAT 08T3), to develop a prediction method for estimating propulsor interaction coefficients. The work was funded under the Ship Performance and Hydromechanics Program and the Work Unit Number was 1500-103.

INTRODUCTION

The interaction between the hull and the propeller is characterized by the thrust-deduction fraction (t), and the thrust-wake fraction (w_T). It is desirable to have a reliable technique for estimating the thrust-deduction fraction and the thrust-wake fraction of twin-screw destroyers. The best method for determining these coefficients is to conduct resistance, propulsion, and open-water experiments. This is not always practical, and the naval architect must often resort to an empirical technique. This report presents a technique for estimating these interaction coefficients from hull-form parameters and propeller characteristics.

The thrust-deduction is defined as the fractional loss of thrust due to the propeller-hull interaction,

$$t = \frac{TH-R}{TH}$$

where TH is the thrust produced by the propeller and R is the towed resistance of the hull without the propeller. The thrust-deduction is usually determined by conducting conventional resistance and self-propulsion model experiments in a towing tank.

The thrust-wake fraction is the integrated velocity defect in way of the propeller. The Taylor wake fraction is deduced from experimental data obtained from an open-water experiment and a propulsion experiment with the same propeller in a towing tank. The wake fraction is determined by computing the thrust coefficient (K_T) and ship speed advance coefficient (J_V) from the propulsion experiment, and by using the open-water curve at the experimental value of K_T to get a value of advance coefficient (J_T). The thrust-wake fraction is then determined from:

$$w_T = 1 - (J_T/J_V) .$$

The thrust-wake fraction and thrust-deduction fraction are dependent on many factors. Therefore, it is difficult to determine which parameters are significant. Wake is affected by hull shape, particularly just forward of the propeller location; propeller geometry, including diameter, pitch, rake, and loading; tip clearance between hull and propeller; distance of propeller tips below the free surface; size, shape, and location of appendages with respect to the propeller; and roughness of the hull surface. The variables which affect the thrust-deduction fraction are generally the same as those listed for the wake. In addition, the size and shape of the rudder and its proximity to the hull, and three propeller characteristics - diameter, radial distribution of loading, and axial position may have an effect on the thrust-deduction fraction.

In 1950, Harvald[1] discussed techniques for estimating the thrust-wake fraction and thrust-deduction fraction of single-screw cargo ships. He evaluated twenty-one different methods used for conventional single-screw cargo ships. He determined that the methods of Taylor[2] and Schoenherr[3] were the best available at that time. He then presented his own method, and concluded that his method as accurate as the Schoenherr method, but easier to use. His final recommendation was to use the Taylor method if a simple technique was satisfactory, and to use his own method if more accuracy was needed.

Grant and Wilson[4] studied the wake and thrust-deduction for 65 twin-screw destroyers. They drew no positive conclusions and did not develop any predictive methods.

[1]References are listed on page 10.

DESCRIPTION OF DATA

Three types of hull-forms were considered as prototypes for this analysis. Data existed from model experiments at DTNSRDC for 150 models of conventional single-screw cargo ships, 65 twin-screw destroyers, and 19 single-screw destroyer escorts. It was decided to begin the analysis with the 65 twin-screw destroyers, since the prediction for this class of ships would be more relevant and useful to the naval architect designing naval combatants. Classes represented by the twin-screw destroyers included the SPRUANCE, FORREST SHERMAN, CHARLES F. ADAMS, AND MITSCHER.

An analysis of existing experimental data on twin-screw destroyers was conducted to determine the effects of twenty-four parameters on the thrust-deduction and thrust-wake fractions. The choice of these parameters was dictated by their availability. The data were correlated with various hull and propeller parameters. The twenty-four independent variables chosen for the interaction prediction model were:

(1) Froude's wetted surface coefficient (Ⓢ),
(2) length-beam ratio (L_{WL}/B_X),
(3) beam-draft ratio (B_X/T_X),
(4) prismatic coefficient (C_P),
(5) half angle of entrance (i_E),
(6) longitudinal center of buoyancy-waterline length ratio ($\overline{FB}/L_{WL}$),
(7) Taylor's 'f' (f_{BT}),
(8) fatness ratio ($\nabla/(0.10L)^3$),
(9) waterplane coefficient (C_{WP}),
(10) longitudinal center of flotation-waterline length ratio ($\overline{FF}/L_{WL}$),
(11) length of parallel middlebody-waterline length ratio (L_P/L_{WL}),
(12) length of entrance-waterline length ratio (L_E/L_{WL}),
(13) afterbody waterplane coefficient (C_{WPA}),
(14) forebody waterplane coefficient (C_{WPF}),
(15) afterbody prismatic coefficient (C_{PA}),
(16) forebody prismatic coefficient (C_{PF}),
(17) entrance prismatic coefficient (C_{PE}),
(18) run prismatic coefficient (C_{PR}),
(19) scale ratio (λ),
(20) propeller diameter-draft ratio (D/T),

(21) projected area-disk area ratio (A_P/A_0),

(22) pitch ratio (P/D),

(23) ship length Reynolds number (R_n), and

(24) Froude number ($V/\sqrt{gL_{WL}}$).

The two dependent variables were thrust-deduction fraction (t) and thrust-wake fraction (w_T). A complete description of the twenty-six variables is presented in Appendix A. The twenty-six parameters from the experiments on the sixty-five models are tabulated in Appendix B.

DESCRIPTION OF COMPUTATIONAL TECHNIQUES

Computer programs developed by the University of California for statistical analysis were used in the analysis of the twin-screw destroyer data. The means, standard deviations, maximum and minimum values were calculated for each of the twenty-six parameters for the sixty-five twin-screw destroyers. Histograms and graphs were also produced using these computer programs. Documentation of these programs is given by Dixon[5].

A correlation matrix was generated for the twenty-four independent variables with the thrust-deduction and wake fractions. The correlation among the hull-form parameters provide a starting point for a statistical evaluation. The values of the correlation coefficient lie between -1 and +1. The magnitude of the correlation coefficient indicates the extent to which the variation of the independent and dependent variables are interrelated. Thus, a correlation coefficient of 0.10 would show very little functional relationship between two variables, while a correlation coefficient of 0.80 would indicate a very strong functional relationship between two variables. The sign of the correlation coefficient indicates how the dependent variable shifts with changes in the independent variable. A positive correlation coefficient indicates that the dependent variable increases along with the independent variable. Conversely, a negative correlation coefficient indicates that the dependent variable decreases as the independent variable increases.

A numerical regression technique determined the significance of each independent variable in the mathematical model. A multiple stepwise regression analysis computer program was used to perform this analysis. This technique contains a built-in procedure for the elimination of redundant or superfluous independent variables from

the regression analysis.

At each stage of the stepwise procedure, the independent variable which yields the greatest improvement in the "goodness" of fit, as measured by the reduction in the standard error of the estimated dependent variable, is entered into the regression equation. Variables entered at earlier stages of the procedure are retested for significance whenever a new variable is entered. A variable may be found significant at an early stage, but may become insignificant after several other variables have entered the regression. Insignificant variables are removed at each stage, prior to the inclusion of the significant variable. Hence, the final form of the regression equation will include only those independent variables that make a significant contribution to the regression equation.

The index of determination gives an estimate of the percentage of "sum of squares" variation in the dependent variable that is explained by the independent variables. The positive square root of this index of determination is called the multiple correlation coefficient.

PRESENTATION OF RESULTS

In general, a numerical model is built from a list of available parameters. Additional parameters can be formed by combining the basic parameters. Principal hull and propeller geometry variables were collected for this study. Originally, a linear model was used in the analysis. Other models, including the logarithmic, exponential, and squared functions of the original data were also investigated. The best results were obtained from the linear model for the thrust-deduction and from the squared model for the thrust-wake fraction.

The following statistics have been computed and tabulated for each of the 24 independent variables (hull-form coefficients) and 2 dependent variables (t and w_T) for the linear model, where X_{ij} represents the i th case of the j th variable and n is the number of models:

(1) Minimum value, Min X_{ij}

(2) Maximum value, Max X_{ij}

(3) Mean, $\overline{X}_j = \frac{1}{n} \sum_{i=1}^{n} X_{ij}$

(4) Standard deviation, $\sigma_j = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (X_{ij} - \overline{X}_j)^2}$

The minimum and maximum values, means, and standard deviations of the twenty-six parameters are presented in Table 1.

Histograms of each variable, indicating the distribution of the data, are shown in Appendix C. This graphical representation of the frequency distribution consists of vertical rectangles whose widths correspond to a definite range of independent variables and whose heights correspond to the number of models with parameters occurring within the range. In general, the distribution of models on the histograms indicate a normal distribution of each of the variables. The variation of the thrust-wake with the thrust-deduction is shown in Figure 1. The fact that the data on this graph show a definite band-like pattern indicates that there is a high degree of correlation between t and w_T. This is confirmed by the fact that the correlation coefficient for these two variables is 0.707.

The variation of the twenty-four independent parameters versus the dependent variables, t and w_T, is shown in graphical form in Appendix D. Each one page graph has fifty units vertically and one hundred units horizontally. The data points are automatically scaled to conform to these dimensions. These figures are presented to show the variation of the basic parameters within the range of data represented. They are not meant to reveal the degree of correlation between each parameter and the experimental data, because the scatter can be due to either the variation of other parameters or due to a weak dependency between the parameter and the data.

Correlation coefficients, between the thrust-deduction (t) and thrust-wake (w_T) fractions and the individual independent parameters, can be compared to assess the relative association of each parameter with t and w_T, while ignoring the influence of the other parameters. The correlation coefficients for the linear model are shown in Table 2. Table 3 presents the correlation coefficients for the squared model.

Examples of highly correlated and poorly correlated variables of the linear model are illustrated graphically in Appendix D. For the linear and squared models, $\overline{FB}/L_{WL}$, C_{WP}, L_E/L_{WL}, C_{PA}, and $V/\sqrt{gL_{WL}}$, indicate the highest correlation with t. The parameters, $\overline{FB}/L_{WL}$, C_{WP}, and C_{WPA} show the highest correlation with w_T. Two of the twenty-four parameters, L_{WL}/B_X and C_{PE}, are relatively statistically uncorrelated with t; and three parameters, S, f_{BT}, and C_{WPF}, are poorly correlated with w_T. Although there is certainly scatter among the data plotted on the figures in Appendix D, there is an obvious trend in the data on some of the figures. This indicates a high degree of correlation between the variables. The obvious "shotgun" effect on some of the plots

in Appendix D, on the other hand, indicates poor correlation.

Upon completion of the correlation studies, sample runs of the stepwise regression program were made to determine the quality of the least squares fit to the data which could be obtained using the twenty-four independent variables to fit t and w_T. After twenty-three steps (the addition of 23 variables), the program achieved maximum accuracy in predicting the thrust-deduction and thrust-wake fractions using the linear model. The resulting mathematical linear models for the thrust-deduction and thrust-wake fractions are given in Tables 4 and 5, respectively. These mathematical models for t and w_T are constructed as the sum of a constant and a number of terms composed of the product of a constant and one variable.

Scale ratio and Reynolds number are included in the regression models. These independent variables are arbitrary parameters whose values can be chosen at will. They indicate that there are probably some scale effects which should be studied further.

The determination indices for the linear model with the most significant parameters were 0.7068 for the thrust-deduction fraction and 0.6763 for the thrust-wake fraction. Parameters contributing to an increase in this index for the linear model for the thrust-deduction fraction were C_{WPA}, $V/\sqrt{gL_{WL}}$, λ, L_E/L_{WL}, i_E, R_n, C_P, D/T, and C_{WPF}; and for the thrust-wake fraction were C_{WP}, D/T, C_{PF}, R_n, P/D, λ, $V/\sqrt{gL_{WL}}$, and L_P/L_{WL}.

Due to the fair results obtained from the linear model, the square of the independent variables was used to construct a new mathematical model for predicting the wake and thrust-deduction factors. The stepwise regression program was again used to analyze the data. This squared model also produced fair results. After 22 steps, the program achieved maximum accuracy in predicting the thrust-deduction factor. Maximum accuracy in predicting the wake fraction was obtained after 23 steps. The resulting squared models for thrust-deduction and wake fraction are given in Tables 6 and 7, respectively.

The determination indices for the squared model with the most significant parameters were 0.6757 for the thrust-deduction fraction and 0.6961 for the thrust-wake fraction. The parameters contributing to an increase in the index of determination for the squared model for the thrust-deduction were $V/\sqrt{gL_{WL}}$, C_{WP}, $\overline{FF}/L_{WL}$, L_E/L_{WL}, A_P/A_O, i_E, λ, and R_n; and for the thrust-wake fraction were C_{WP}, C_{PF}, D/T, and P/D.

DISCUSSION OF RESULTS

The mathematical models which have resulted from the use of stepwise regression are certainly more complex than the simple formulas given by Taylor. However, if use is made of the computer, the method is no more complex than Harvald's method. The one thing which must be emphasized with regard to the formulas is that they are valid only for the range of independent variables for which they were derived. Any attempt to employ these formulas for a parameter value outside the domain of definition of these functions may result in erroneous and misleading results.

The question of the accuracy of the present method can only be considered by looking at the prediction errors obtained by using the method. In order to obtain such data, the regression models were used to predict the values of 1-t and $1-w_T$ for the 65 ships used in the analysis. Similar calculations were made using the simplified formula from Taylor. This was done in order that the performance of the regression method could be gauged relative to another method.

The results of the predictions of 1-t and $1-w_T$, using the regression models and Taylor's model, have been divided by the measured values of these parameters, and the resulting values have been plotted as histograms. The histograms for 1-t from the regression models and Taylor's formula are plotted on Figures 2 and 3. Similar data for $1-w_T$ are plotted on Figures 4 and 5. These figures show the number of predictions which fall within one percent intervals of error. Values less than 1.0 indicate that 1-t or $1-w_T$, are under-predicted and values greater than 1.0 indicate that 1-t and $1-w_T$ are over-predicted.

A comparison of the predictors of 1-t and $1-w_T$, using the regression equations and Taylor's formula given in Figures 2 through 5, shows that the regression model results resemble a normal distribution and are fairly narrow, while the results of Taylor's formula are of almost uniform height and distributed over a much wider range. Analysis of the means and standard deviations of these distributions, given in Tables 8 and 9 show that the means for all formulas, except Taylor's 1-t and $1-w_T$, are very close to one. This signifies that these formulas are on the average correct, except for Taylor's 1-t and $1-w_T$ formulas. The standard deviation of Taylor's formula is more than twice that of the regression formulas. This indicates that the probability of obtaining a given accuracy of prediction is twice as high for the regression models as for Taylor's formula (assuming the means are correct).

CONCLUSIONS AND RECOMMENDATIONS

This investigation attempted to develop a technique for estimating the thrust-deduction and thrust-wake fractions. Data for 65 ships representing a variety of twin-screw destroyers were assembled and used in the analysis. Results of this study obtained by statistical method demonstrated that the multiple regression analysis technique does not predict these interaction coefficients for twin-screw destroyers with reasonable accuracy.

The correlation of the thrust-deduction and thrust-wake fractions with the twenty-four independent variables was unsatisfactory. The analysis revealed a relatively low correlation - below 0.5 in the majority of the parameters and often a value close to zero. The thrust-wake fraction, however, was highly correlated with the thrust-deduction fraction.

One reason for the poor estimation from this method is possibly that the method does not contain a sufficient number or type of parameters to adequately describe the variations of ship and propeller geometry within the range of data represented. No parameters representing propeller loading distribution were used, as there was insufficient information of the loading distributions for the propeller in the data sample. Addition of parameters such as the propeller tip clearance, the location of the propeller centerline relative to the ship's baseline, the size of the propeller hub compared to the propeller diameter, the size of the rudders, and propeller-to-rudder clearance might improve the prediction technique. Deletion of some parameters might also be considered.

With the data available at DTNSRDC for other classes of ships, a reasonable technique might be developed utilizing common ship parameters as input to a regression analysis scheme. Further progress might be achieved by investigating other numerical models, such as the cross-products of the parameters. The results of predictions using other mathematical models or other classes of ships might satisfactorily estimate the thrust-deduction and thrust-wake fractions.

Careful statistical analysis of the data can yield significant insight into the importance of individual hull-form parameters and establish trends. Future efforts will be required to obtain a better prediction method to estimate the interaction coefficients.

REFERENCES

1. Harvald, S.A., "Wake of Merchant Ships," Danish Technical Press, Copenhagen, (1950).

2. Taylor, D.W., "The Speed and Power of Ships," United States Maritime Commission (1943).

3. Schoenherr, K.E., "Propulsion and Propellers," Principles of Naval Architecture, Vol. 2, (1939).

4. Grant, J.W. and Wilson, C.J., "Design Practices for Powering Predictions," DTNSRDC Ship Performance Department Report, SPD-693-01, (October 1976).

5. Dixon, W. J., "Biomedical Computer Programs," University of California Press, Los Angeles, (1973).

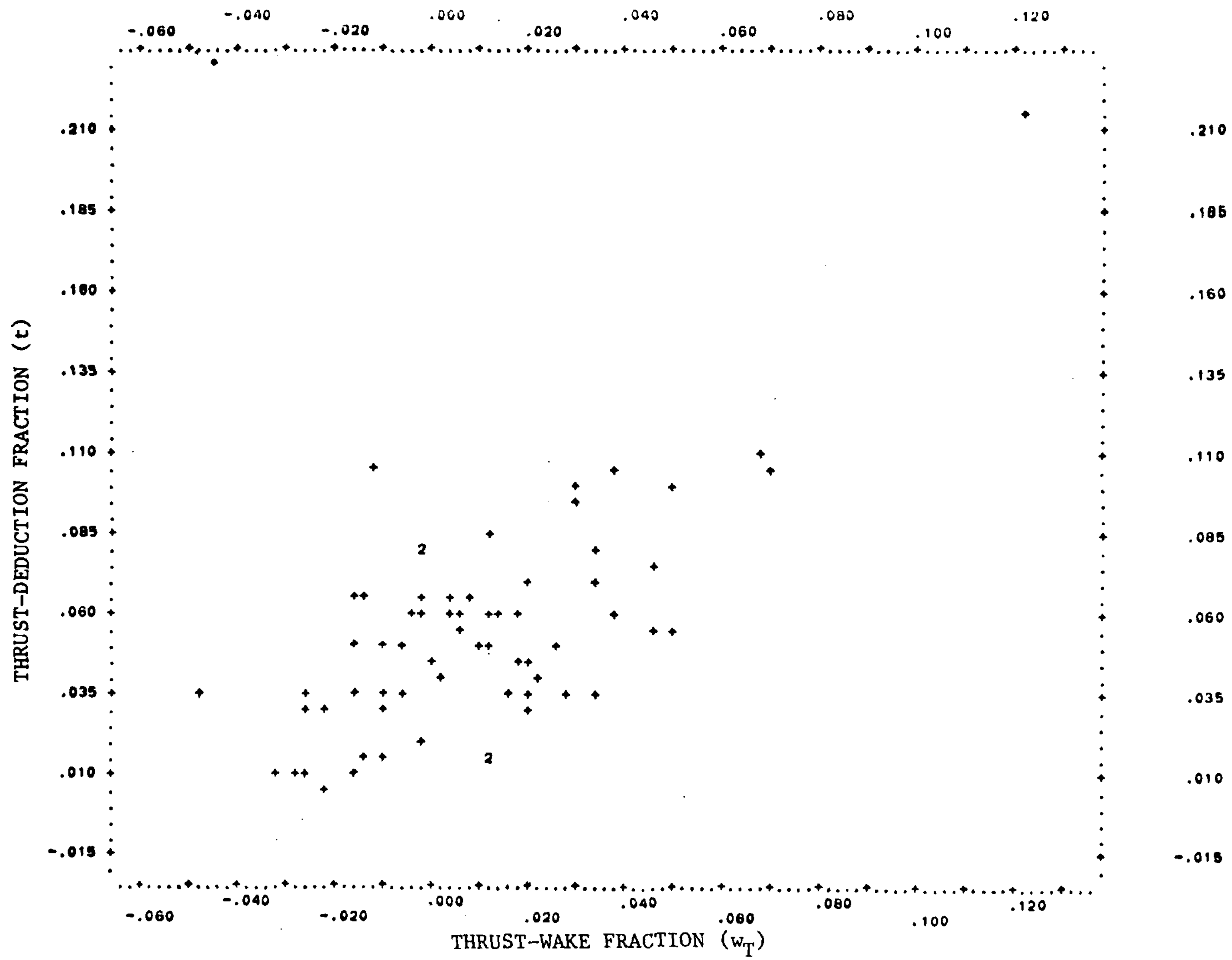


Figure 1 - Variation of Thrust-Wake Fraction and Thrust-Deduction Fraction

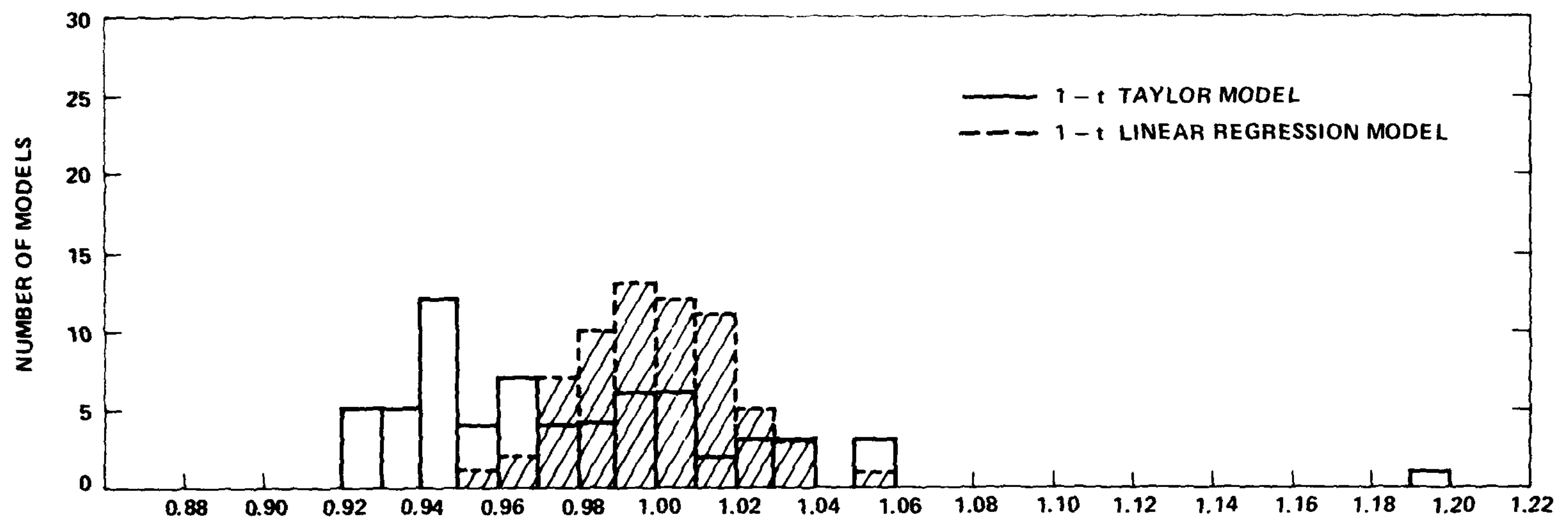


Figure 2 - Distribution of Error in Thrust-Deduction Fraction From Linear Regression and Taylor Models

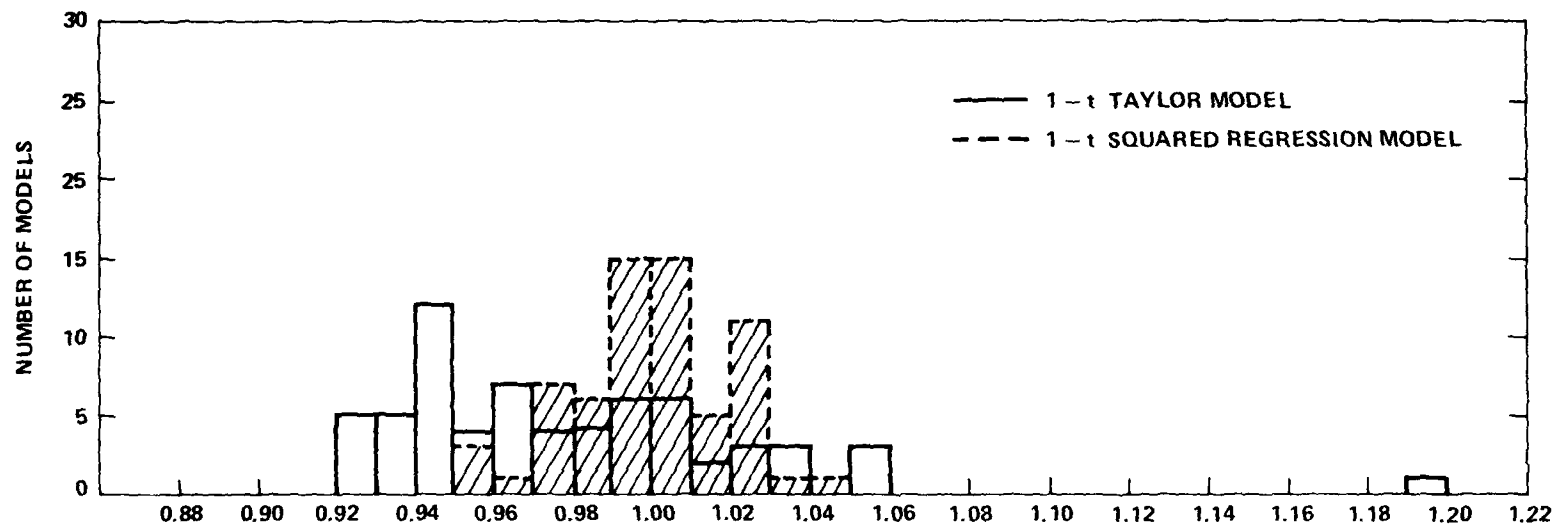


Figure 3 - Distribution of Error in Thrust-Deduction Fraction From Squared Regression and Taylor Models

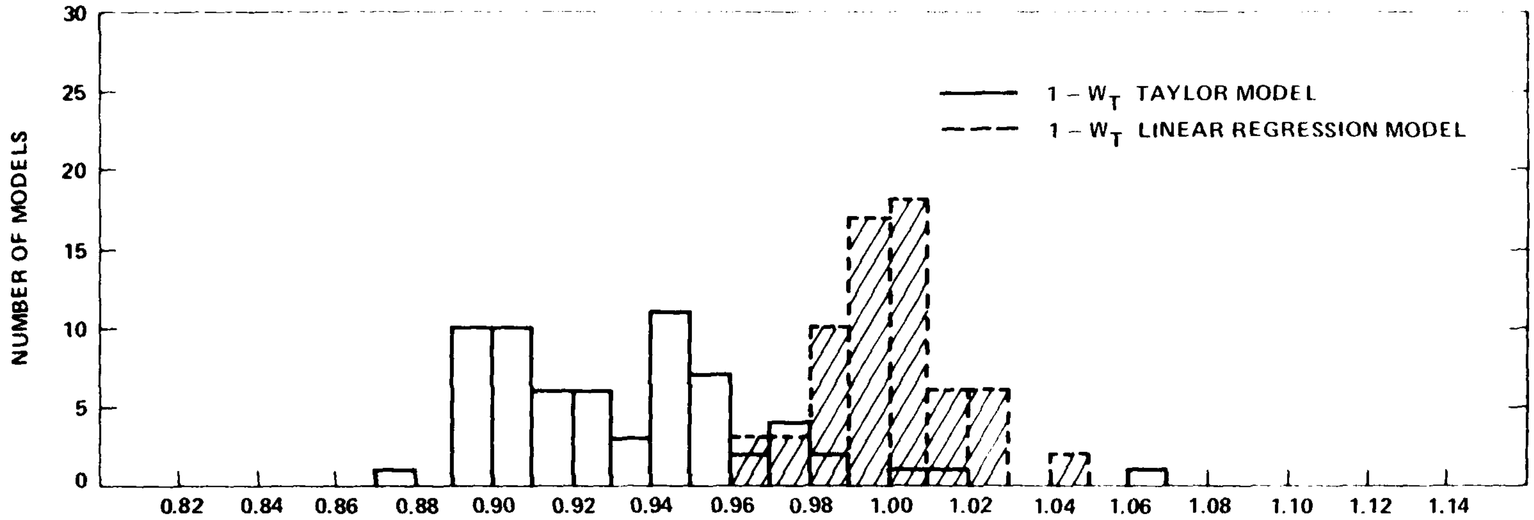


Figure 4 - Distribution of Error in Thrust-Wake Fraction From Linear Regression and Taylor Models

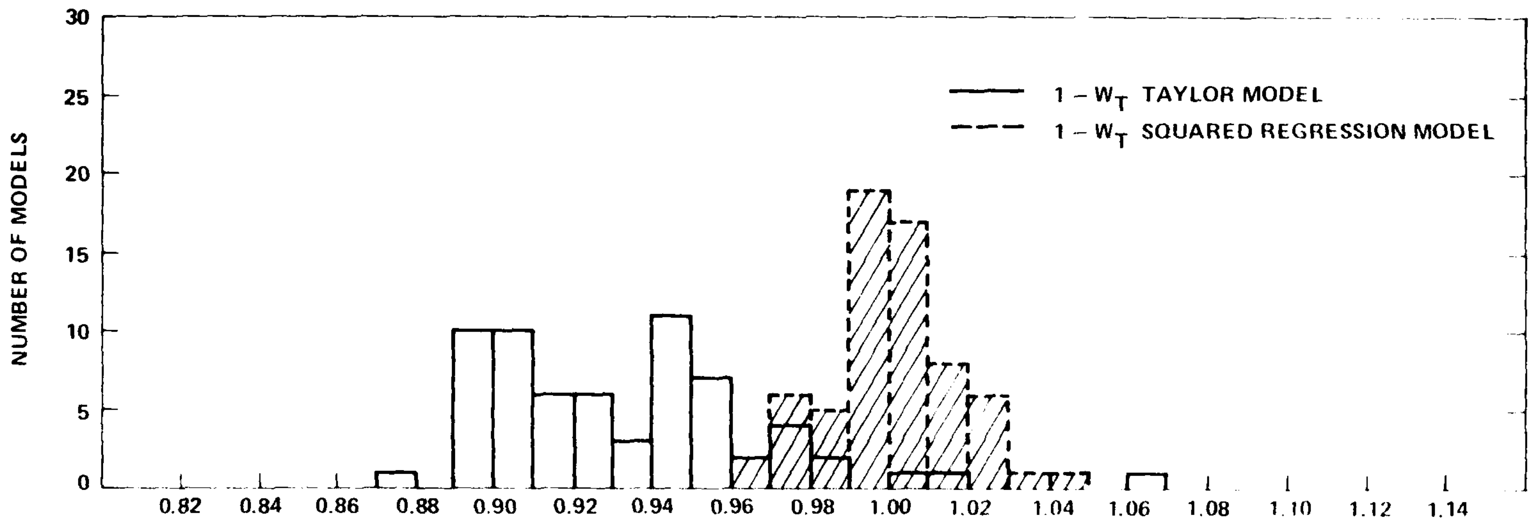


Figure 5 - Distribution of Error in Thrust-Wake Fraction From Squared Regression and Taylor Models

TABLE 1

STATISTICAL PARAMETERS FOR BASIC VARIABLES REPRESENTING TWIN-SCREW DESTROYERS

Parameter	Minimum	Maximum	Mean	Standard Deviation
Ⓢ	7.245	8.234	7.689	0.221
L_{WL}/B_X	8.313	10.460	9.538	0.466
B_X/T_X	2.717	3.650	3.171	0.192
C_P	0.560	0.672	0.614	0.026
i_E	4.000	12.000	8.126	1.967
$\overline{FB}/L_{WL}$	0.488	0.523	0.510	0.008
f_{BT}	0.000	0.600	0.120	0.166
$\nabla/(0.10L)^3$	1.358	2.154	1.756	0.222
C_{WP}	0.681	0.775	0.742	0.022
$\overline{FF}/L_{WL}$	0.514	0.588	0.559	0.015
L_P/L_{WL}	0.000	0.036	0.006	0.013
L_E/L_{WL}	0.498	0.555	0.533	0.017
C_{WPA}	0.713	0.962	0.875	0.047
C_{WPF}	0.559	0.694	0.618	0.032
C_{PA}	0.593	0.717	0.650	0.027
C_{PF}	0.531	0.660	0.587	0.030
C_{PE}	0.557	0.682	0.609	0.026
C_{PR}	0.541	0.693	0.616	0.029
λ	13.000	26.000	20.502	3.586
D/T	0.732	1.141	0.933	0.096
A_P/A_O	0.461	0.816	0.674	0.070
P/D	0.892	1.457	1.106	0.105
$R_n \times 10^{-9}$	0.948	2.291	1.817	0.331
$V/\sqrt{gL_{WL}}$	0.352	0.586	0.477	0.067
t	0.003	0.215	0.054	0.033
w_T	-0.049	0.121	0.009	0.028

TABLE 2

CORRELATION COEFFICIENTS FOR LINEAR VARIABLES

Parameter	t	w_T
S	0.115	-0.000
L_{WL}/B_X	-0.007	0.198
B_X/T_X	-0.082	-0.189
C_P	-0.073	-0.025
i_E	-0.298	-0.189
$\overline{FB}/L_{WL}$	-0.375	-0.356
f_{B_T}	0.177	0.023
$\nabla/(0.10L)^3$	-0.050	-0.156
C_{WP}	-0.355	-0.491
$\overline{FF}/L_{WL}$	-0.138	-0.332
L_P/L_{WL}	-0.210	-0.173
L_E/L_{WL}	-0.402	-0.308
C_{WPA}	-0.292	-0.479
C_{WPF}	-0.111	0.014
C_{PA}	-0.381	-0.313
C_{PF}	0.135	0.188
C_{PE}	-0.004	0.090
C_{PR}	-0.062	-0.070
λ	0.320	0.095
D/T	-0.330	-0.330
A_P/A_O	-0.104	-0.189
P/D	0.058	0.065
$R_n \times 10^{-9}$	0.022	-0.106
$V/\sqrt{gL_{WL}}$	-0.405	-0.274
t		0.707

TABLE 3

CORRELATION COEFFICIENTS FOR SQUARED VARIABLES

Parameter	t	w_T
Ⓢ	0.113	-0.003
L_{WL}/B_X	0.002	0.202
B_X/T_X	-0.078	-0.184
C_P	-0.073	-0.025
i_E	-0.277	-0.181
$\overline{FB}/L_{WL}$	-0.377	-0.356
f_{BT}	0.089	-0.028
$\nabla/(0.10L)^3$	-0.030	-0.149
C_{WP}	-0.347	-0.484
$\overline{FF}/L_{WL}$	-0.124	-0.321
L_P/L_{WL}	-0.210	-0.173
L_E/L_{WL}	-0.401	-0.306
C_{WPA}	-0.264	-0.460
C_{WPF}	0.105	0.017
C_{PA}	-0.380	-0.313
C_{PF}	0.137	0.190
C_{PE}	-0.005	0.088
C_{PR}	-0.059	-0.068
λ	0.333	0.098
D/T	-0.323	-0.321
A_P/A_O	-0.107	-0.193
P/D	0.064	0.073
$R_n \times 10^{-18}$	0.044	-0.075
$V/\sqrt{gL_{WL}}$	-0.398	0.276
t		0.707

TABLE 4

LISTING OF COEFFICIENTS FOR LINEAR REGRESSION MODEL
FOR THRUST-DEDUCTION FRACTION
(Constant (4.62328))

Step Number	Variable	Coefficient
1	$V/\sqrt{gL_{WL}}$	-0.23790
2	C_{WPA}	-1.04237
3	λ	0.00935
4	R_n	-0.09146
5	C_P	-5.35383
6	i_E	-0.00507
7	D/T	-0.10526
8	$\nabla/(0.10L)^3$	-0.18314
9	C_{WP}	3.26399
10	C_{WPF}	-2.10433
11	C_{PF}	-3.91022
12	f_{BT}	-0.08448
13	P/D	-0.01213
14	L_P/L_{WL}	0.19808
15	B_X/T_X	-0.01470
16	Ⓢ	-0.06031
17	A_P/A_O	0.06016
18	$\overline{FB}/L_{WL}$	0.14966
19	C_{PA}	3.09229
20	C_{PE}	7.10020
21	L_E/L_{WL}	-5.08389
22	L_{WL}/B_X	-0.03141
23	$\overline{FF}/L_{WL}$	-2.80978

TABLE 5

LISTING OF COEFFICIENTS FOR LINEAR REGRESSION MODEL
FOR THRUST-WAKE FRACTION
(Constant (-2.00197))

Step Number	Variable	Coefficient
1	C_{WP}	-1.94003
2	D/T	-0.12594
3	C_{PF}	-1.57986
4	R_n	-0.06369
5	P/D	0.04278
6	$V/\sqrt{gL_{WL}}$	-0.07447
7	L_{WL}/B_X	0.03678
8	λ	0.00482
9	L_P/L_{WL}	0.02936
10	C_{WPF}	1.83502
11	C_{PE}	1.72391
12	A_P/A_O	0.03560
13	L_E/L_{WL}	-0.83611
14	$\overline{FF}/L_{WL}$	4.64832
15	C_{WPA}	-0.52694
16	C_{PA}	0.15639
17	f_{BT}	-0.01121
18	Ⓢ	0.02383
19	$\nabla/(0.10L)^3$	0.06829
20	B_X/T_X	0.02339
21	$\overline{FB}/L_{WL}$	-0.50293
22	i_E	-0.00018
23	C_{PR}	0.04754

TABLE 6

LISTING OF COEFFICIENTS FOR SQUARED REGRESSION MODEL
FOR THRUST-DEDUCTION FRACTION
(Constant (0.24509))

Step Number	Variable	Coefficient
1	L_E/L_{WL}	0.02958
2	i_E	-0.00022
3	A_P/A_O	0.01583
4	$V/\sqrt{gL_{WL}}$	-0.21889
5	$\overline{FF}/L_{WL}$	-0.18688
6	λ	0.00030
7	R_n	-0.03038
8	D/T	-0.05969
9	C_P	1.17300
10	$\nabla/(0.10L)^3$	0.01372
11	L_P/L_{WL}	7.67789
12	B_X/T_X	0.01268
13	L_{WL}/B_X	0.00286
14	f_{BT}	-0.09411
15	C_{WPF}	0.02902
16	C_{PA}	-0.17861
17	C_{PF}	-0.86020
18	$\overline{FB}/L_{WL}$	-1.67830
19	P/D	-0.00631
20	S	-0.00090
21	C_{WP}	-0.07393
22	C_{WPA}	-0.03500

TABLE 7

LISTING OF COEFFICIENTS FOR SQUARED REGRESSION MODEL
FOR THRUST-WAKE FRACTION
(Constant (1.91713))

Step Number	Variable	Coefficient
1	C_{WP}	-0.67262
2	C_{PF}	-5.32083
3	D/T	-0.06741
4	R_n	-0.01450
5	P/D	0.01381
6	$V/\sqrt{gL_{WL}}$	-0.08095
7	L_{WL}/B_X	0.00081
8	λ	0.00011
9	f_{BT}	-0.07827
10	C_{PE}	9.76818
11	L_P/L_{WL}	-5.86386
12	C_{WPF}	0.53347
13	$\overline{FF}/L_{WL}$	1.13789
14	L_E/L_{WL}	-7.73494
15	A_P/A_O	0.03523
16	$\nabla/(0.10L)^3$	0.00752
17	S	0.00107
18	B_X/T_X	-0.00023
19	C_{WPA}	-0.09262
20	C_P	-7.91557
21	C_{PA}	3.92659
22	$\overline{FB}/L_{WL}$	-1.52020
23	i_E	0.00003

TABLE 8

STATISTICAL VALUES FOR ERROR DISTRIBUTION OF THRUST-DEDUCTION AND THRUST-WAKE FRACTIONS USING LINEAR REGRESSION MODEL

PARAMETER	MEAN	STANDARD DEVIATION
$\frac{(1-t)\ \text{Predicted}}{(1-t)\ \text{Experimental}}$	1.0004	0.0193
$\frac{(1-t)\ \text{Taylor}}{(1-t)\ \text{Experimental}}$	0.9790	0.0449
$\frac{(1-w_T)\ \text{Predicted}}{(1-w_T)\ \text{Experimental}}$	1.0003	0.0162
$\frac{(1-w_T)\ \text{Taylor}}{(1-w_T)\ \text{Experimental}}$	0.9336	0.0350

TABLE 9

STATISTICAL VALUES FOR ERROR DISTRIBUTION OF THRUST-DEDUCTION AND THRUST-WAKE FRACTIONS USING SQUARED REGRESSION MODEL

PARAMETER	MEAN	STANDARD DEVIATION
$\frac{(1-t)\ \text{Predicted}}{(1-t)\ \text{Experimental}}$	1.0000	0.0202
$\frac{(1-t)\ \text{Taylor}}{(1-t)\ \text{Experimental}}$	0.9790	0.0449
$\frac{(1-w_T)\ \text{Predicted}}{(1-w_T)\ \text{Experimental}}$	1.0010	0.0159
$\frac{(1-w_T)\ \text{Taylor}}{(1-w_T)\ \text{Experimental}}$	0.9336	0.0350

TABLE A-1

DESCRIPTION OF INDEPENDENT AND DEPENDENT VARIABLES

1. Ⓢ Froude's Wetted Surface Coefficient

$$Ⓢ = \frac{S}{\nabla_T^{2/3}},$$

where S is wetted surface and ∇_T is total displaced volume

2. $\frac{L_{WL}}{B_X}$ Length-Beam Ratio,

where L_{WL} is waterline length and B_X is maximum beam at waterline

3. $\frac{B_X}{T_X}$ Beam-Draft Ratio,

where B_X is maximum beam and T_X is maximum draft

4. C_P Prismatic Coefficient,

$$C_P = \frac{\nabla_T}{L_{WL}\ A_X}$$

where ∇_T is total displacement volume, L_{WL} is waterline length, and A_X is maximum section area

5. i_E Half Angle of Entrance

in degrees, of waterline at bow with reference to centerplane

6. $\overline{FB}/L_{WL}$

Ratio of longitudinal center of buoyancy from forward perpendicular to waterline length

7. f_{BT} Taylor sectional area coefficient for bulbous bow

$$f_{BT} = \frac{A_{BT}}{A_X}$$

Ratio of sectional area curve at FP to sectional area at maximum section

8. $\nabla/(0.10L)^3$ Fatness Ratio

where displaced volume (∇) is for salt water and length is on the waterline

9. C_{WP} Waterplane Coefficient

$$C_{WP} = \frac{A_W}{L_{WL}\ B_X}$$

where A_W is total waterplane area, L_{WL} is waterline length, and B_X is maximum beam at waterline

10. $\overline{FF}/L_{WL}$,

Longitudinal center of flotation aft of Forward Perpendicular, as fraction of length on waterline

11. L_P/L_{WL},

Length of parallel middlebody as fraction of waterline length

12. L_E/L_{WL},

Length of entrance as fraction of waterline length

13. C_{WPA} Afterbody Waterplane Coefficient

$$C_{WPA} = \frac{A_{WA}}{L_A\ B_X}$$

where A_{WA} is the waterplane area of the afterbody, L_A is one-half of L_{WL} or length of the afterbody, and B_X is maximum beam at the waterline

14. C_{WPF} Forebody Waterplane Coefficient

$$C_{WPF} = \frac{A_{WF}}{L_F\ B_X}$$

where A_{WF} is the waterplane area of the forebody, L_F is one-half of L_{WL} or length of the forebody, and B_X is maximum beam at waterline

15. C_{PA} Afterbody Prismatic Coefficient

$$C_{PA} = \frac{\nabla_A}{L_A\, A_M}$$

where L_A is one-half of L_{WL} or length of the afterbody, ∇_A is volume of the afterbody and A_M is midship-section area

16. C_{PF} Forebody Prismatic Coefficient

$$C_{PF} = \frac{\nabla_F}{L_F\, A_M}$$

where L_F is one-half of L_{WL} or length of the forebody, ∇_F is volume of the forebody, and A_M is midship-section area

17. C_{PE} Entrance Prismatic Coefficient

$$C_{PE} = \frac{\nabla_E}{L_E\, A_X}$$

where L_E is the length of entrance, ∇_E is the volume of entrance, and A_X is maximum section area

18. C_{PR} Run Prismatic Coefficient

$$C_{PR} = \frac{\nabla_R}{L_R\, A_X}$$

where L_R is the length of run, ∇_R is the volume of run, and A_X is maximum section area

19. λ Scale Ratio

Length of ship to length of model scale ratio

20. D/T Propeller Diameter - Draft Ratio

Ratio of ship propeller diameter to ship draft

21. A_P/A_O Projected Area - Disk Area Ratio

Projected area ratio of blades of propeller (outside of hub) to disk area

22. P/D Pitch Ratio

Ratio of propeller pitch to propeller diameter

23. R_n Ship Length Reynolds Number

$$R_n = \frac{V \cdot L_{WL}}{(\nu)}$$

where V is design speed, and L_{WL} is length of waterline, and ν is kinematic viscosity of salt water at 59^{o}F

24. $V/\sqrt{gL_{WL}}$ Froude number

Design speed divided by the square root of the gravitational acceleration and length on the waterline

25. t Thrust-deduction fraction

26. w_T Taylor wake fraction determined from thrust identity

Ⓢ	L/B	B/T	C_P	i_E	$\overline{FB}/L_{WL}$	f_{BT}	Δ - L	C_{WP}	$\overline{FF}/L_{WL}$	L_P/L	L_E/L	C_{WPA}	C_{WPF}	C_{PA}	C_{PF}
7.682	10.175	3.357	0.628	9.0	0.497	0.0	38.79	0.681	0.514	0.0	0.505	0.713	0.650	0.627	[illegible]
7.682	10.175	3.357	0.628	9.0	0.497	0.0	38.79	0.681	0.514	0.0	0.505	0.713	0.652	0.627	[illegible]
7.587	9.794	3.344	0.616	8.5	0.515	0.0	46.37	0.740	0.549	0.0	0.550	0.853	0.631	0.661	[illegible]
7.587	9.794	3.344	0.616	8.5	0.515	0.0	46.37	0.740	0.549	0.0	0.550	0.853	0.631	0.661	[illegible]
7.923	10.132	3.263	0.592	7.0	0.514	0.0	40.85	0.741	0.557	0.0	0.550	0.871	0.622	0.641	[illegible]
7.720	9.569	3.284	0.594	8.5	0.513	0.02	45.78	0.735	0.556	0.0	0.550	0.870	0.621	0.643	[illegible]
7.918	10.309	3.208	0.600	9.0	0.513	0.02	41.43	0.752	0.560	0.0	0.550	0.879	0.621	0.647	[illegible]
7.717	9.541	3.155	0.600	9.0	0.515	0.04	48.86	0.741	0.556	0.0	0.550	0.876	0.628	[illegible]	[illegible]
7.717	9.541	3.155	0.600	9.0	0.515	0.04	48.86	0.741	0.556	0.0	0.550	0.876	0.628	[illegible]	[illegible]
7.717	9.541	3.155	0.600	9.0	0.515	0.04	48.86	0.741	0.556	0.0	0.550	0.876	0.628	0.635	[illegible]
7.662	9.524	3.111	0.617	9.0	0.516	0.02	50.22	0.750	0.560	0.0	0.550	0.887	0.622	0.664	[illegible]
7.662	9.524	3.111	0.617	9.0	0.516	0.02	50.22	0.750	0.560	0.0	0.550	0.887	0.622	0.664	[illegible]
7.771	9.785	3.650	0.643	12.0	0.500	0.00	41.92	0.763	0.537	0.0	0.500	0.841	0.685	0.647	[illegible]
7.626	9.985	3.497	0.672	12.0	0.509	0.001	46.94	0.775	0.538	0.0	0.500	0.856	0.694	0.694	[illegible]
7.417	9.050	3.135	0.618	9.5	0.519	0.000	57.28	0.748	0.560	0.0	0.525	0.884	0.623	0.666	[illegible]
7.482	9.453	3.117	0.633	9.5	0.518	0.028	54.30	0.758	0.560	0.036	0.530	0.889	0.633	0.679	[illegible]
7.482	9.453	3.117	0.633	9.5	0.518	0.028	54.30	0.758	0.560	0.036	0.530	0.889	0.633	0.679	[illegible]
7.482	9.453	3.117	0.633	9.5	0.518	0.028	54.30	0.758	0.560	0.036	0.530	0.889	0.633	0.679	[illegible]
7.482	9.453	3.117	0.633	9.5	0.518	0.028	54.30	0.758	0.560	0.036	0.530	0.889	0.633	0.679	[illegible]
7.482	9.453	3.117	0.633	9.5	0.518	0.028	54.30	0.758	0.560	0.036	0.530	0.889	.633	0.679	[illegible]
7.482	9.453	3.117	0.633	9.5	0.518	0.028	54.30	0.758	0.560	0.036	0.530	0.889	0.633	0.679	[illegible]
7.482	9.453	3.117	0.633	9.5	0.518	0.028	54.30	0.758	0.560	0.036	0.530	0.889	0.633	0.679	[illegible]
7.482	9.453	3.117	0.633	9.5	0.518	0.028	54.30	0.758	0.560	0.036	0.530	0.889	0.633	0.679	[illegible]
7.296	9.105	3.090	0.614	9.5	0.519	0.020	57.13	0.752	0.561	0.000	0.555	0.889	0.625	0.67[illegible]	[illegible]
7.324	10.138	2.834	0.627	8.5	0.500	0.000	48.99	0.692	0.520	0.000	0.499	0.734	0.649	0.631	[illegible]
7.365	10.460	2.717	0.646	10.0	0.523	0.000	47.56	0.755	0.551	0.000	0.547	0.883	0.652	0.717	[illegible]
7.278	9.095	3.374	0.649	11.0	0.513	0.000	57.36	0.773	0.544	0.000	0.525	0.866	0.683	0.682	[illegible]
7.779	10.162	3.088	0.629	9.0	0.509	0.010	46.85	0.751	0.549	0.000	0.513	0.858	0.650	0.657	[illegible]
7.726	9.690	3.148	0.611	8.0	0.515	0.030	41.24	0.725	0.562	0.000	0.550	0.863	0.599	0.661	[illegible]
7.825	9.662	3.000	0.572	5.6	0.505	0.054	47.00	0.703	0.566	0.000	0.522	0.849	0.565	0.593	[illegible]
7.812	9.934	3.423	0.612	8.5	0.516	0.023	41.50	0.743	0.560	0.000	0.547	0.887	0.620	0.663	[illegible]
7.917	9.934	3.423	0.633	8.5	0.500	0.480	43.01	0.741	0.559	0.000	0.547	0.885	0.619	0.663	[illegible]
7.959	9.934	3.423	0.654	8.5	0.488	0.60	44.42	0.742	0.560	0.0	0.547	0.885	0.619	0.663	0.660
7.311	9.198	3.046	0.627	12.0	0.515	0.00	57.71	0.770	0.553	0.0	0.500	0.882	0.659	0.662	0.593
7.482	9.453	3.117	0.633	9.5	0.518	0.028	54.30	0.758	0.560	0.036	0.530	0.889	0.633	0.679	0.584
7.815	9.453	3.117	0.667	9.5	0.496	0.39	57.13	0.758	0.560	0.036	0.530	0.889	0.633	0.679	0.655
7.925	9.839	3.162	0.560	4.0	0.515	0.00	40.54	0.712	0.570	0.0	0.537	0.875	0.573	0.603	0.532
8.143	9.839	3.162	0.564	4.0	0.512	0.17	40.82	0.712	0.570	0.0	0.537	0.875	0.573	0.603	[illegible]
8.009	9.736	3.145	0.561	5.5	0.515	0.0	40.61	0.711	0.571	0.0	0.537	0.876	0.568	0.603	0.531
7.245	8.930	3.135	0.636	10.75	0.509	0.0	60.67	0.765	0.551	0.0	0.518	0.873	0.658	0.657	0.616
7.382	8.930	3.135	0.644	10.75	0.503	0.26	61.43	0.765	0.551	0.0	0.518	0.873	0.658	0.657	0.632
7.777	9.624	3.210	0.585	6.00	0.507	0.07	45.52	0.724	0.567	0.0	0.500	0.872	0.577	0.609	0.561
7.754	9.496	3.074	0.587	4.50	0.506	0.19	48.04	0.724	0.574	0.0	0.550	0.897	0.575	0.614	0.563
7.921	9.496	3.074	0.594	4.50	0.501	0.33	48.60	0.724	0.574	0.0	0.550	0.897	0.575	0.614	0.576
7.537	9.650	2.891	0.604	5.50	0.521	0.0	52.39	0.737	0.567	0.0	0.525	0.894	0.598	0.654	0.557
7.762	9.650	2.891	0.617	5.50	0.511	0.33	53.50	0.737	0.567	0.0	0.525	0.894	0.598	0.654	0.584
7.616	9.506	2.807	0.629	5.50	0.505	0.30	57.99	0.754	0.569	0.0	0.518	0.907	0.610	0.643	0.617
7.700	9.545	3.066	0.576	4.50	0.501	0.26	49.85	0.734	0.563	0.0	0.534	0.880	0.608	0.594	0.569
8.234	9.847	3.505	0.644	6.5	0.489	0.58	44.23	0.741	0.575	0.0	0.544	0.931	0.586	0.655	0.651
7.670	9.494	2.928	0.614	6.6	0.503	0.28	53.90	0.756	0.567	0.0	0.525	0.903	0.616	0.630	0.603
7.742	8.607	3.342	0.573	7.0	0.517	0.283	54.96	0.710	0.573	0.0	0.550	0.884	0.564	0.642	0.535
7.986	9.722	3.000	0.562	5.5	0.501	0.33	46.51	0.724	0.579	0.0	0.550	0.901	0.559	0.597	0.549
8.129	8.600	3.242	0.615	7.0	0.500	0.48	59.44	0.768	0.588	0.0	0.525	0.962	0.580	0.640	0.622
7.904	8.585	3.128	0.607	7.0	0.513	0.34	61.53	0.771	0.587	0.0	0.525	0.960	0.583	0.649	0.575
7.904	8.585	3.128	0.607	7.0	0.513	0.34	61.53	0.771	0.587	0.0	0.525	0.960	0.583	0.649	0.575
7.900	8.333	3.503	0.592	6.5	0.501	0.32	55.28	0.724	0.566	0.0	0.500	0.861	0.586	0.606	0.578
7.748	9.055	3.017	0.633	9.0	0.514	0.30	59.08	0.767	0.571	0.0	0.550	0.931	0.618	0.673	0.597
7.867	9.640	2.821	0.575	7.0	0.512	0.29	52.48	0.736	0.582	0.0	0.550	0.917	0.562	0.628	0.545
7.867	9.640	2.821	0.575	7.0	0.512	0.29	52.48	0.736	0.582	0.0	0.550	0.917	0.562	0.628	0.545
7.632	9.213	3.155	0.626	6.0	0.515	0.0	52.28	0.755	0.562	0.0	0.525	0.883	0.628	0.659	0.596
7.647	8.313	3.609	0.615	10.0	0.515	0.025	56.71	0.718	0.556	0.0	0.550	0.833	0.622	0.654	0.579
7.549	10.119	3.278	0.625	9.0	0.496	0.0	40.51	0.681	0.515	0.0	0.498	0.713	0.650	0.622	0.628
7.587	9.794	3.344	0.616	8.5	0.515	0.0	46.37	0.740	0.549	0.0	0.550	0.853	0.631	0.661	0.576
7.587	9.794	3.344	0.616	8.5	0.515	0.0	46.37	0.740	0.549	0.0	0.550	0.853	0.631	0.661	0.576
7.923	10.132	3.263	0.592	7.0	0.514	0.0	40.85	0.741	0.557	0.0	0.550	0.871	0.622	0.641	0.564

1

TABLE B-1

SUMMARY OF MODEL PARTICULARS AND BASIC PARAMETERS

C_{WPA}	C_{WPF}	C_{PA}	C_{PF}	C_{PE}	C_{PR}	SCALE	D/T	A_P/A_0	P/D	Ship Reynolds Number x 10^{-9}	$V/\sqrt{L}$	t	w_T
0.713	0.650	0.627	0.630	0.633	0.623	15.5	0.9890	0.595	1.102	1.2286	1.701	0.110	0.067
0.713	0.650	0.627	0.630	0.633	0.623	15.5	1.0989	0.608	1.200	1.2286	1.701	0.100	0.070
0.853	0.631	0.661	0.576	0.612	0.620	16.7	1.0780	0.670	1.090	1.5834	1.970	0.030	-0.022
0.853	0.631	0.661	0.576	0.612	0.620	16.7	1.0780	0.638	1.090	1.5834	1.970	0.012	-0.026
0.871	0.622	0.641	0.564	0.594	0.590	18.6	0.9218	0.630	1.170	1.7145	1.815	[illegible]	-0.026
0.870	0.620	0.643	0.565	0.595	0.592	16.7	1.0583	0.680	1.100	1.5394	1.915	0.015	-0.028
0.879	0.621	0.647	0.569	0.601	0.600	18.6	1.0000	0.685	1.076	1.7635	1.867	0.049	-0.016
0.876	0.628	0.655	0.572	0.599	0.602	16.7	0.9845	0.634	1.0974	1.2854	1.548	0.019	-0.016
0.876	0.628	0.655	0.572	0.599	0.602	16.7	1.0066	0.655	1.055	1.2854	1.548	0.036	0.015
0.876	0.628	0.655	0.572	0.599	0.602	16.7	1.0066	0.655	1.055	1.2854	1.548	0.014	0.011
0.887	0.622	0.669	0.579	0.611	0.625	18.45	0.9020	0.726	1.068	1.7007	1.822	0.012	0.022
0.887	0.622	0.669	0.579	0.611	0.625	18.45	0.9237	0.747	1.0797	1.7007	1.822	0.003	-0.023
0.841	0.685	0.647	0.640	0.640	0.647	17.40	1.0769	0.624	1.254	1.6497	1.930	0.060	0.012
0.856	0.694	0.694	0.650	0.650	0.693	18.20	0.9856	0.711	1.276	1.7505	1.913	0.060	0.006
0.884	0.623	0.668	0.574	0.592	0.648	18.45	0.9231	0.686	1.042	1.6521	1.770	0.031	0.020
0.889	0.633	0.679	0.588	0.612	0.629	18.45	0.9423	0.589	1.027	1.7148	1.737	0.039	0.001
0.889	0.633	0.679	0.588	0.612	0.629	18.45	0.9231	0.700	1.070	1.7148	1.737	0.045	0.017
0.889	0.633	0.679	0.588	0.612	0.629	18.45	1.0346	0.472	1.200	1.7148	1.737	0.037	-0.007
0.889	0.633	0.679	0.588	0.612	0.629	18.45	1.0385	0.765	1.043	1.7148	1.737	0.016	-0.0[illegible]
0.889	0.633	0.679	0.588	0.612	0.629	18.45	1.1408	0.665	1.225	1.7148	1.737	0.015	-0.01
0.889	0.633	0.679	0.588	0.612	0.629	18.45	0.9423	0.589	1.027	1.7148	1.737	0.016	0.011
0.889	0.633	0.679	0.588	0.612	0.629	18.45	0.9231	0.700	1.070	1.7148	1.737	0.067	-0.016
0.889	0.633	0.679	0.588	0.612	0.629	18.45	0.9231	0.700	1.070	1.7148	1.737	0.035	-0.010
0.889	0.625	0.670	0.576	0.610	0.619	18.45	0.9276	0.698	1.000	1.6524	1.770	0.050	0.026
0.734	0.649	0.631	0.624	0.623	0.632	15.50	0.8449	0.560	1.109	1.3139	1.812	0.033	0.034
0.883	0.652	0.717	0.601	0.623	0.673	20.572	0.8699	0.670	1.132	2.0215	1.817	0.058	0.003
0.866	0.683	0.682	0.619	0.636	0.663	18.200	0.9664	0.680	1.195	1.6378	1.778	0.050	0.010
0.856	0.650	0.650	0.610	0.619	0.640	19.685	0.8528	0.790	1.202	1.6843	1.601	0.055	0.049
0.863	0.599	0.661	0.575	0.607	0.616	22.500	0.8732	0.650	1.072	2.1333	1.697	0.037	0.028
0.849	0.565	0.593	0.553	0.571	0.573	26.000	1.0217	0.706	1.227	2.2597	1.447	0.046	0.020
0.887	0.620	0.663	0.574	0.605	0.620	23.800	0.9943	0.730	1.060	2.2879	1.673	0.012	-0.012
0.885	0.619	0.663	0.618	0.644	0.620	23.800	0.9943	0.730	1.060	2.2879	1.650	0.049	-0.006
0.885	0.619	0.663	0.660	0.682	0.620	23.8	0.9943	0.730	1.060	2.2879	1.673	0.030	-0.010
0.882	0.659	0.660	0.593	0.593	0.660	20.372	0.9125	0.806	1.044	1.7687	1.636	0.035	-0.026
0.889	0.633	0.679	0.589	0.612	0.629	13.0	1.0384	0.791	1.037	1.5131	1.277	0.051	-0.011
0.889	0.633	0.679	0.655	0.674	0.629	13.0	1.0384	0.791	1.037	1.5131	1.277	0.060	0.017
0.875	0.573	0.603	0.532	0.558	0.563	23.942	0.8889	0.730	1.060	2.2584	1.581	0.037	0.020
0.875	0.573	0.603	0.540	0.565	0.563	23.942	0.8889	0.730	1.060	2.2584	1.581	0.066	-0.003
0.876	0.568	0.605	0.531	0.557	0.565	23.942	0.8889	0.685	1.083	2.2584	1.581	0.060	-0.005
0.873	0.658	0.657	0.616	0.628	0.644	21.524	0.9000	0.686	1.105	1.8251	1.610	0.034	-0.016
0.873	0.658	0.657	0.632	0.643	0.644	21.524	0.9000	0.679	1.146	1.8251	1.610	0.047	-0.001
0.872	0.577	0.609	0.561	0.561	0.609	22.706	0.8182	0.816	1.369	2.2162	1.461	0.066	-0.015
0.897	0.575	0.614	0.563	0.601	0.569	24.064	0.8108	0.675	1.047	2.1333	1.291	0.080	0.033
.897	0.575	0.614	0.576	0.613	0.569	24.064	0.8108	0.675	1.047	2.1333	1.291	0.105	0.038
0.894	0.598	0.654	0.557	0.578	0.611	22.706	0.7447	0.765	0.952	2.0725	1.310	0.100	0.030
0.894	0.598	0.654	0.584	0.601	0.633	22.706	0.7447	0.765	0.952	2.0725	1.310	0.076	0.046
0.907	0.610	0.643	0.617	0.629	0.629	24.064	0.7389	0.675	1.047	2.0687	1.246	0.094	0.030
0.880	0.608	0.594	0.569	0.591	0.559	24.064	0.7317	0.675	1.047	2.2913	1.184	0.101	0.049
0.931	0.586	0.655	0.651	0.671	0.612	23.8	1.0102	0.730	1.060	2.2879	1.670	0.021	-0.002
0.903	0.616	0.630	0.603	0.619	0.609	24.064	0.7317	0.675	1.047	2.2518	1.257	0.072	0.019
0.884	0.564	0.642	0.535	0.563	0.585	25.511	0.8767	0.686	1.105	2.2123	1.397	0.065	0.004
0.901	0.559	0.597	0.549	0.579	0.541	24.636	0.9167	0.615	1.021	2.1155	1.335	0.060	-0.002
0.962	0.580	0.640	0.602	0.615	0.614	25.512	0.9697	0.679	1.146	[illegible]	1.399	0.080	-0.002
0.960	0.583	0.649	0.575	0.590	0.626	25.512	0.9357	0.679	1.146	1.8184	1.398	0.104	-0.013
0.960	0.583	0.649	0.575	0.590	0.626	25.512	0.9357	0.679	1.146	1.8184	1.398	0.080	-0.003
0.861	0.586	0.606	0.578	0.578	0.606	25.500	0.9457	0.726	1.175	1.9753	1.342	0.066	0.008
0.931	0.618	0.673	0.597	0.631	0.634	24.064	0.7317	0.675	1.047	2.2123	1.268	0.068	0.033
0.917	0.562	0.628	0.545	0.576	0.574	24.824	0.8718	0.575	1.457	2.0946	1.303	0.062	0.037
0.917	0.562	0.628	0.545	0.576	0.574	24.824	0.8718	0.575	1.457	2.0946	1.303	0.050	0.012
0.883	0.628	0.659	0.596	0.614	0.639	24.824	1.0119	0.575	1.457	1.9290	1.358	0.085	0.012
0.873	0.622	0.659	0.579	0.614	0.617	15.000	0.8500	0.461	0.892	0.9481	1.386	0.055	0.005
0.713	0.650	0.622	0.628	0.627	0.624	22.143	0.9574	0.595	1.102	1.2286	1.704	0.215	0.121
0.853	0.631	0.661	0.576	0.612	0.620	16.700	1.0127	0.630	1.080	1.5834	1.970	0.035	-0.049
0.853	0.631	0.661	0.576	0.612	0.620	16.700	1.0127	0.630	1.080	1.5834	1.970	0.060	0.014
0.871	0.622	0.641	0.564	0.594	0.590	18.600	0.9218	0.610	1.170	1.7145	1.815	0.055	0.045

PRECEDING PAGE BLANK-NOT FILMED

APPENDIX C

FREQUENCY DISTRIBUTION OF INDEPENDENT AND DEPENDENT VARIABLES FOR TWIN-SCREW DESTRYOYERS

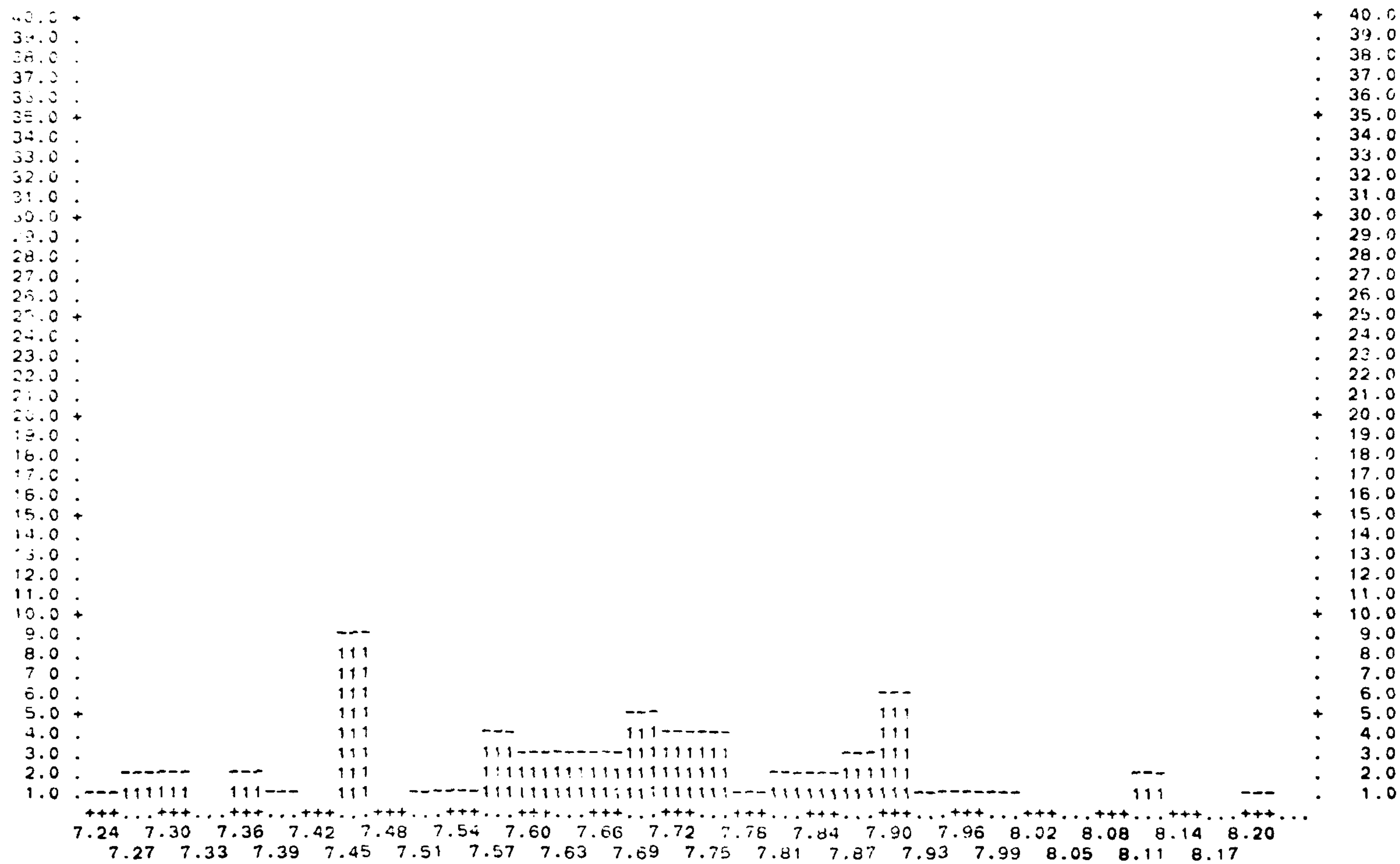


Figure C-1 - Frequency Distribution of the Wetted Surface Coefficient for Twin-Screw Destroyers

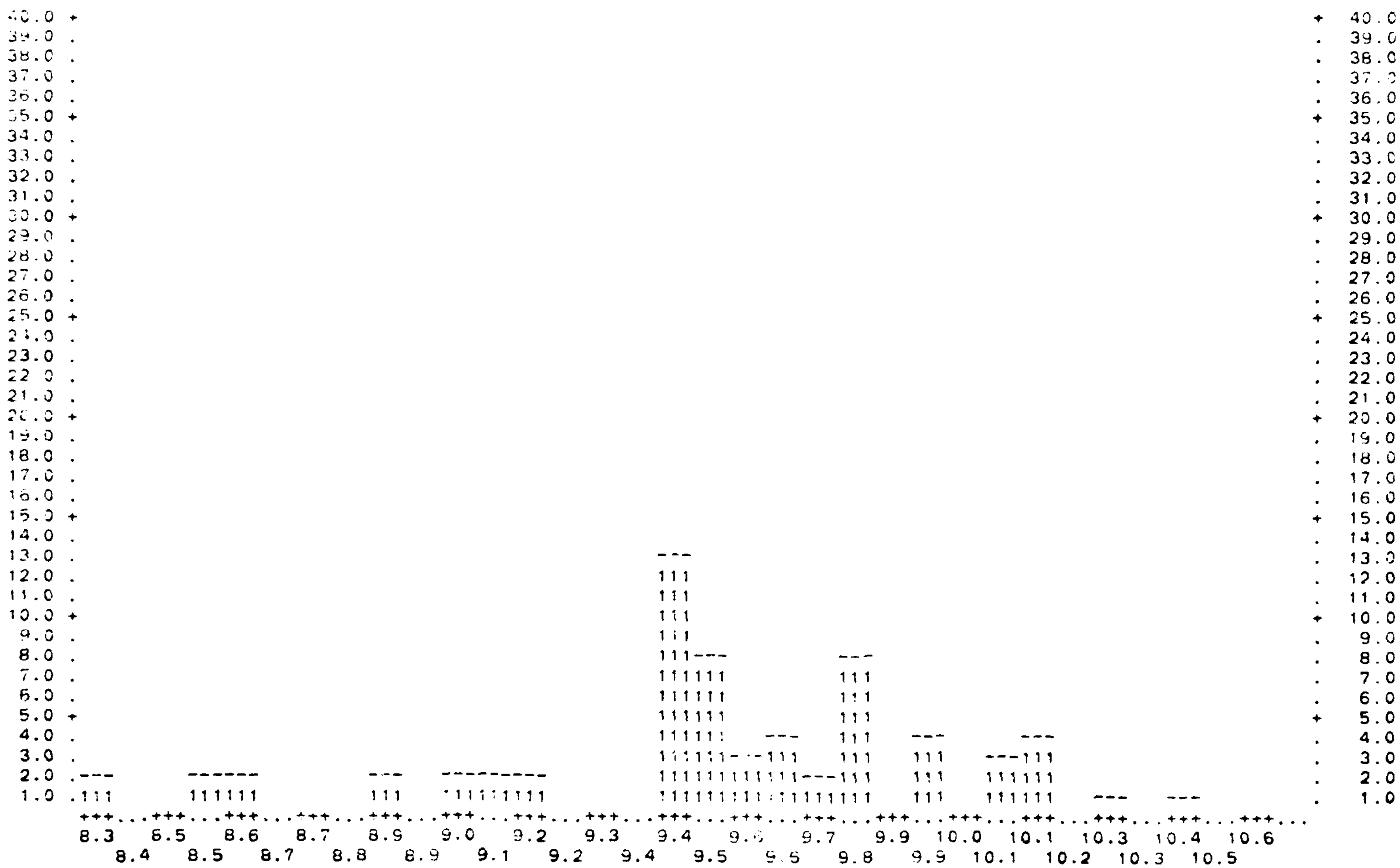


Figure C-2 - Frequency Distribution of the Length-Beam Ratio for Twin-Screw Destroyers

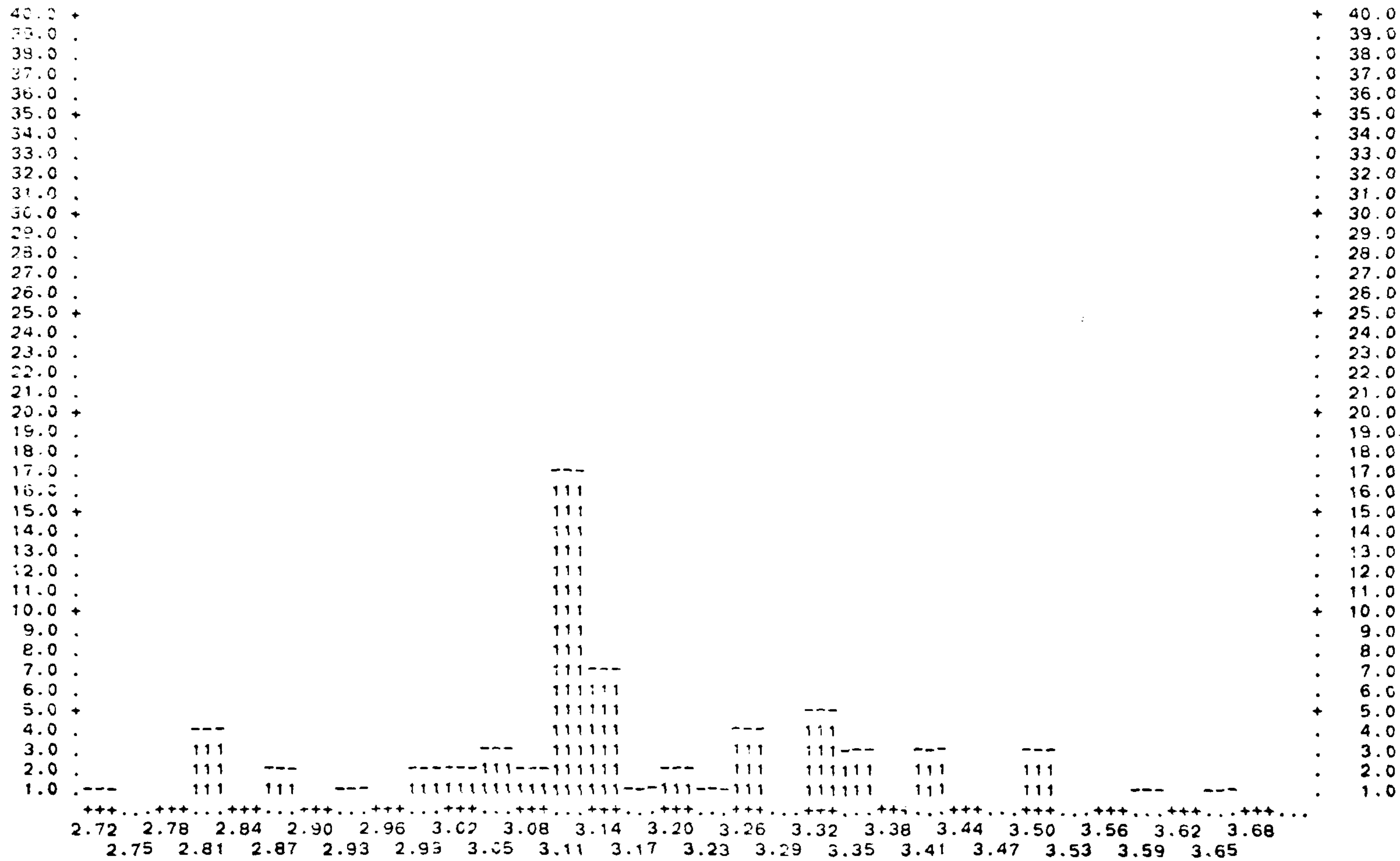


Figure C-3 - Frequency Distribution of the Beam-Draft Ratio for Twin-Screw Destroyers

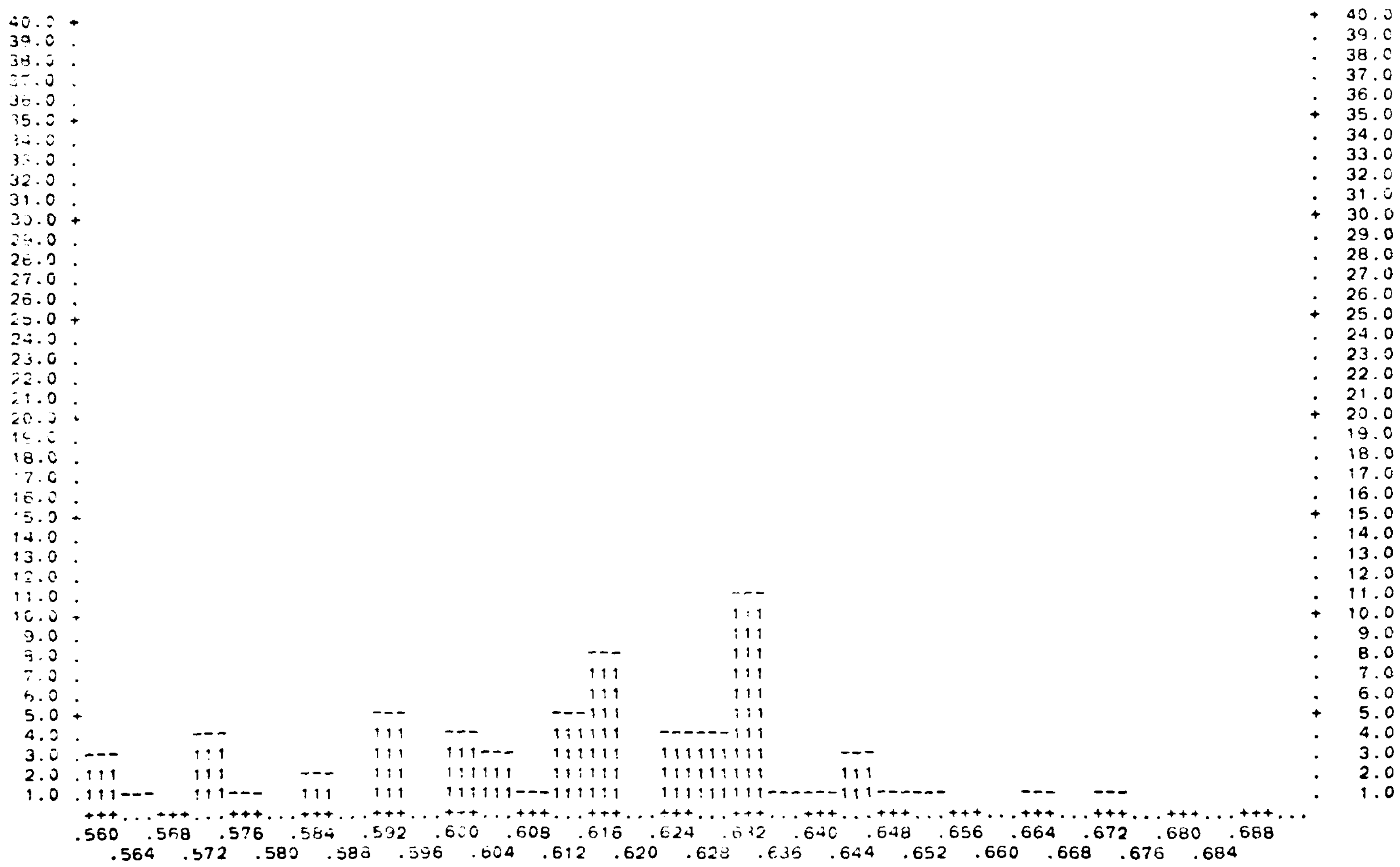


Figure C-4 - Frequency Distribution of the Prismatic Coefficient for Twin-Screw Destroyers

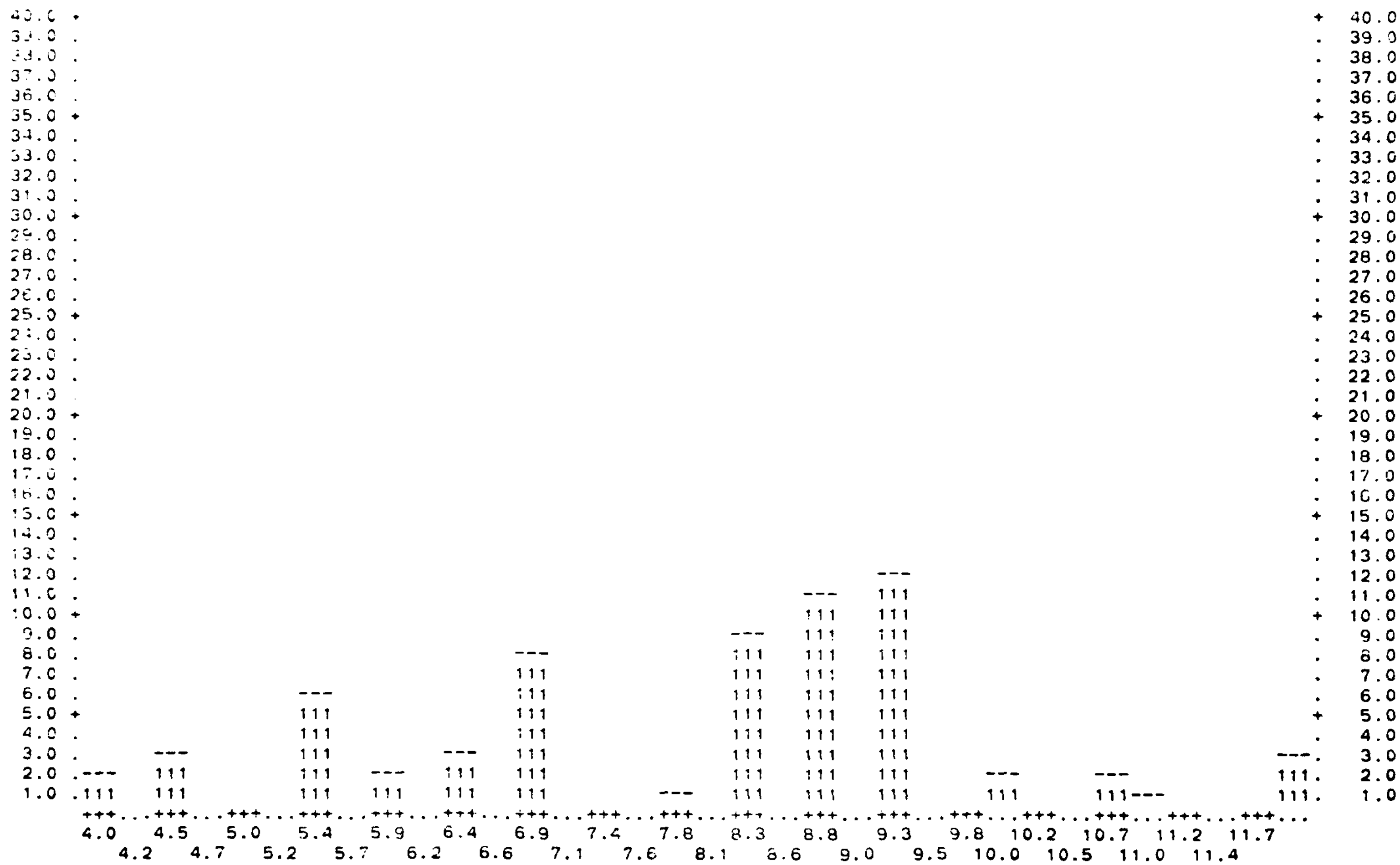


Figure C-5 - Frequency Distribution of the Half Angle of Entrance for Twin-Screw Destroyers

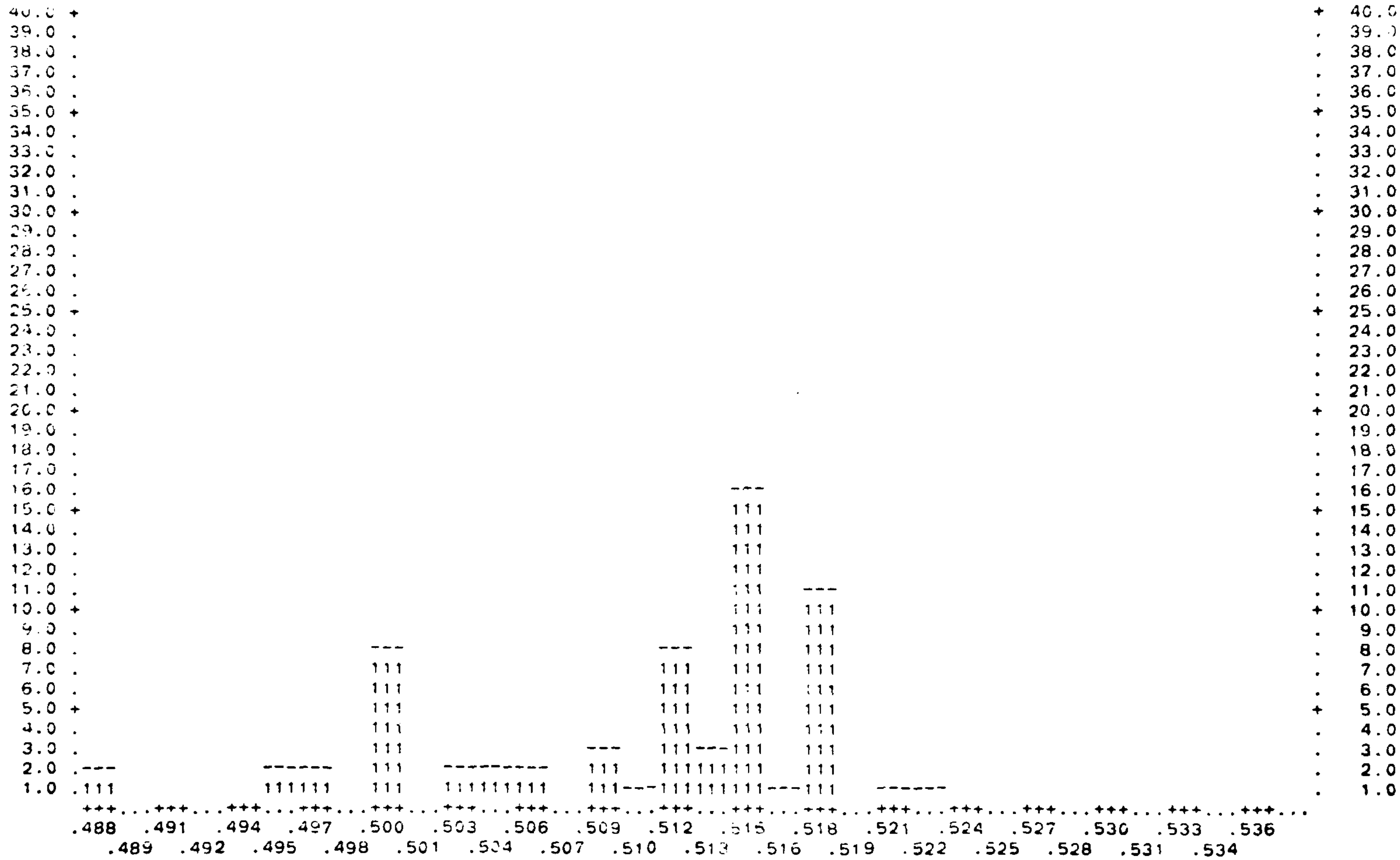


Figure C-6 - Frequency Distribution of the Longitudinal Center of Buoyancy-Waterline Length Ratio for Twin-Screw Destroyers

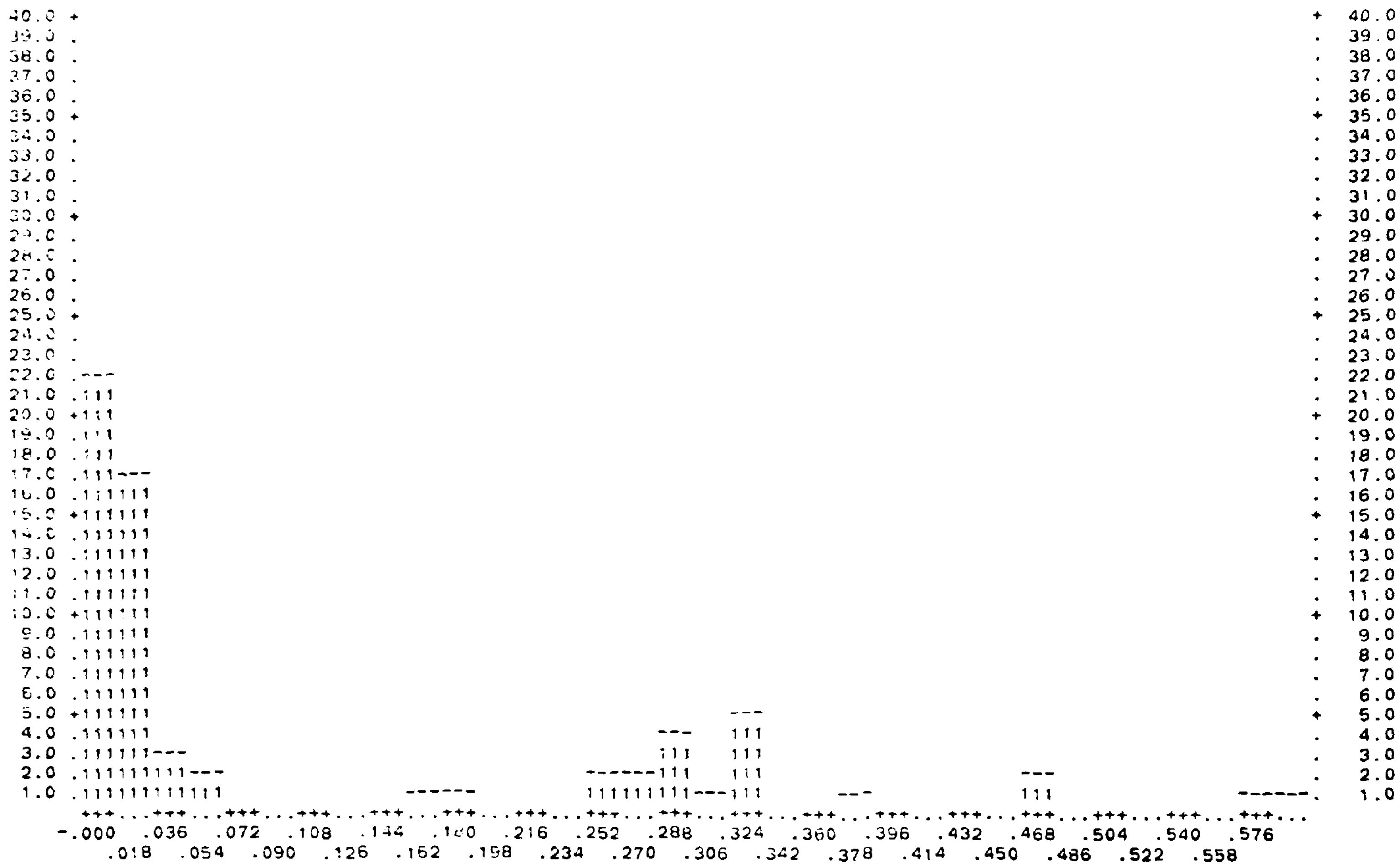


Figure C-7 - Frequency Distribution of Taylor's 'f' for Twin-Screw Destroyers

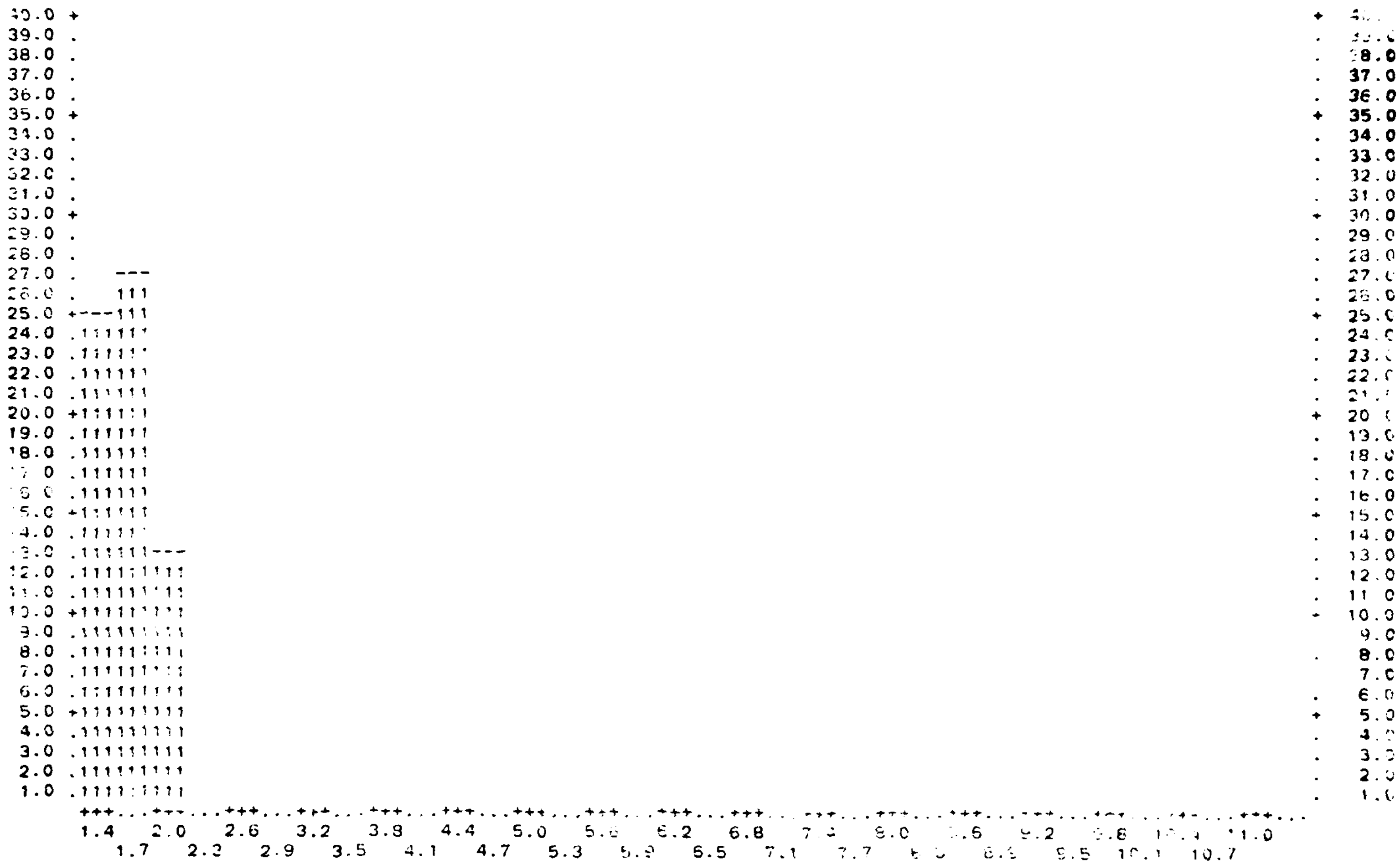


Figure C-8 - Frequency Distribution of the Fatness Ratio for Twin-Screw Destroyers

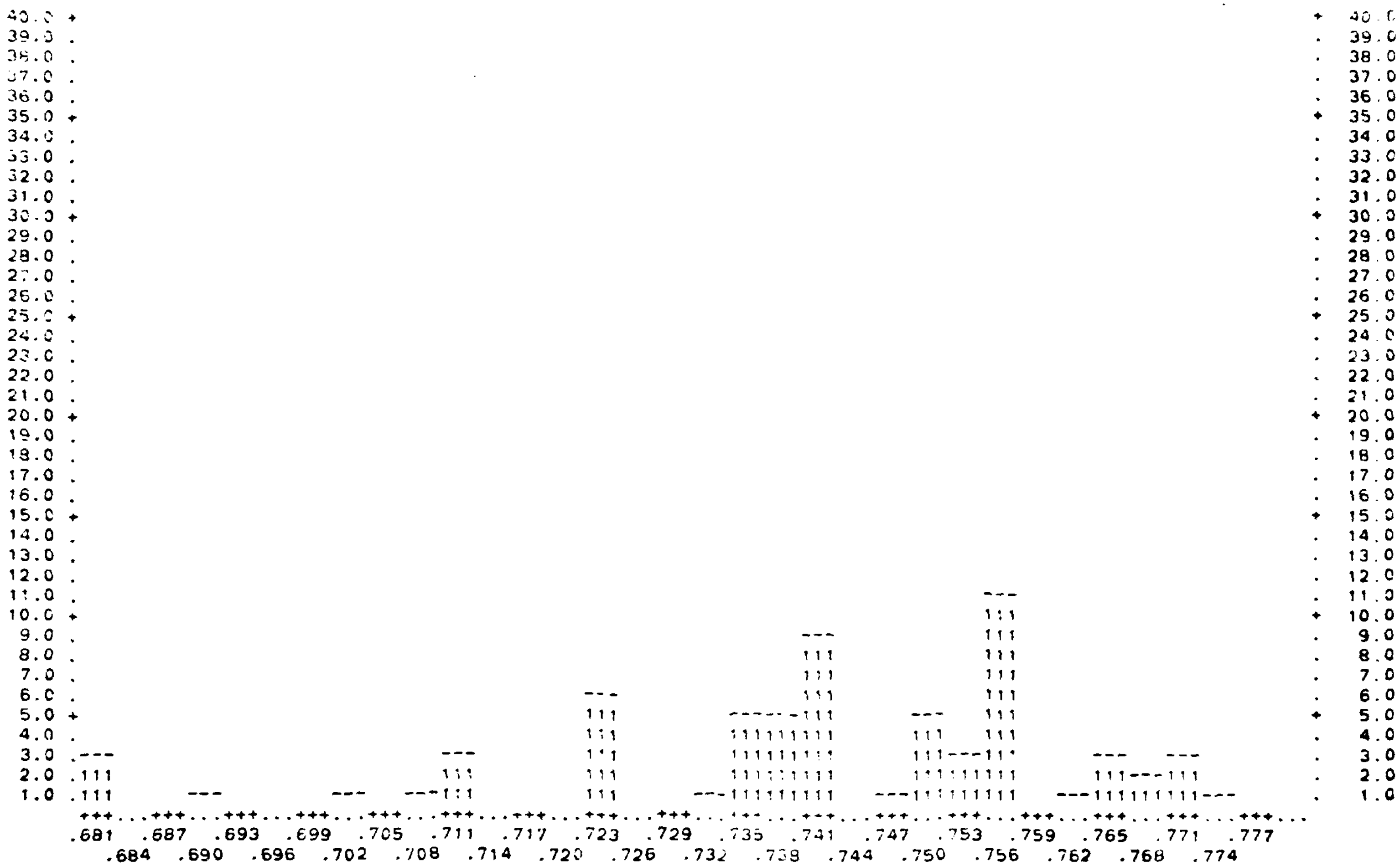


Figure C-9 - Frequency Distribution of the Waterplane Coefficient for Twin-Screw Destroyers

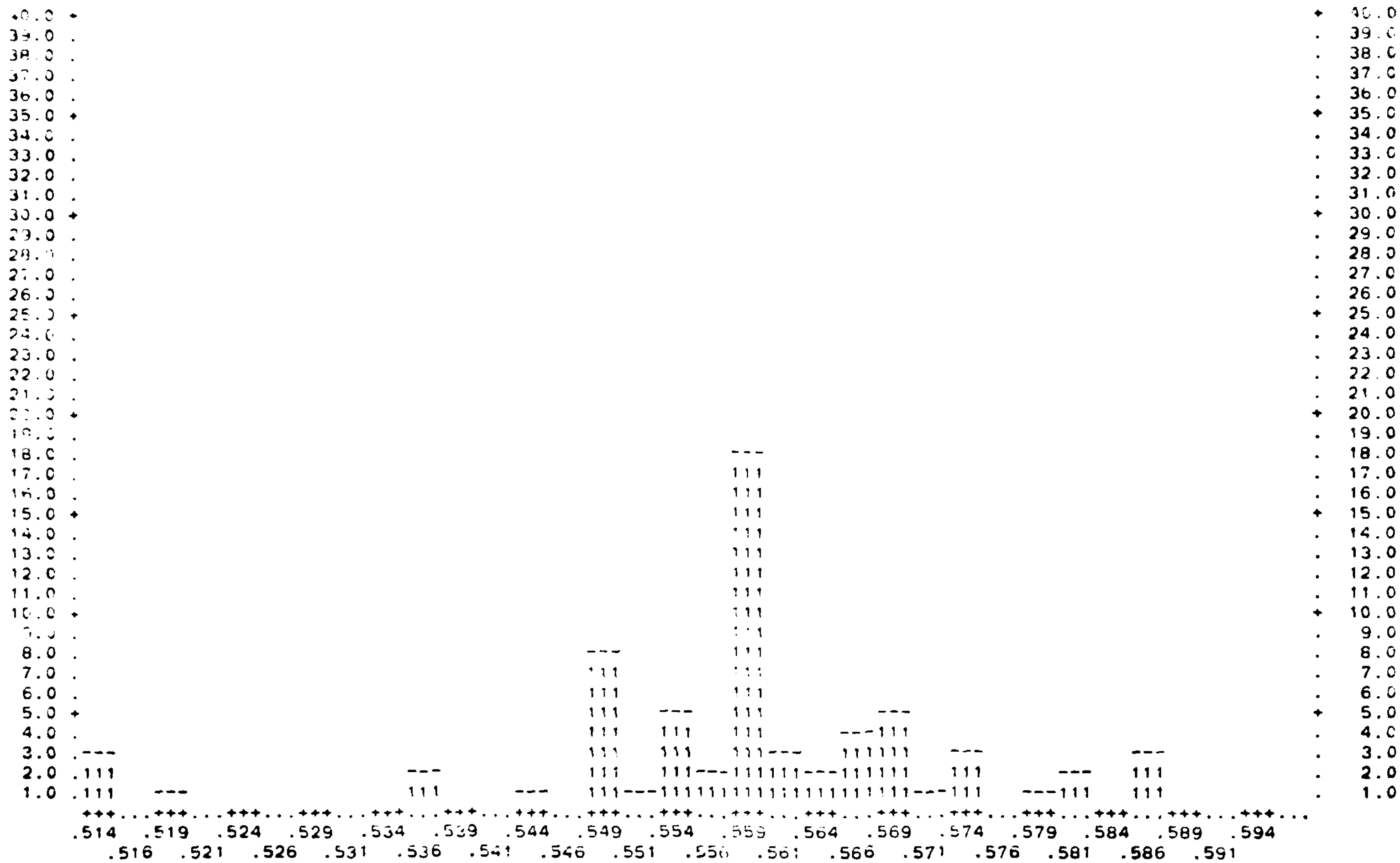


Figure C-10 - Frequency Distribution of the Longitudinal Center of Flotation-Waterline Length Ratio for Twin-Screw Destroyers

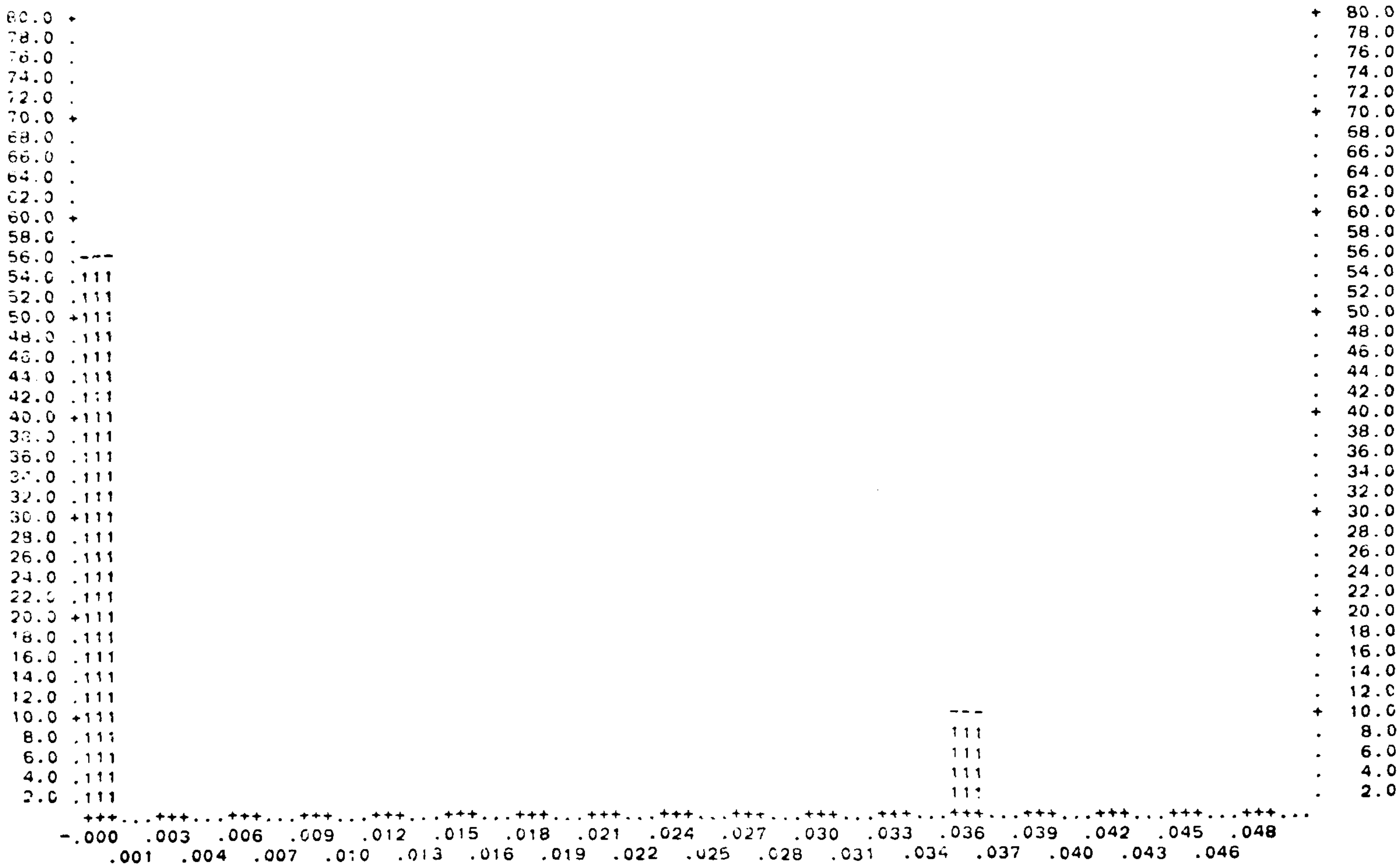


Figure C-11 - Frequency Distribution of the Length of Parallel Middlebody-Waterline Length Ratio for Twin-Screw Destroyers

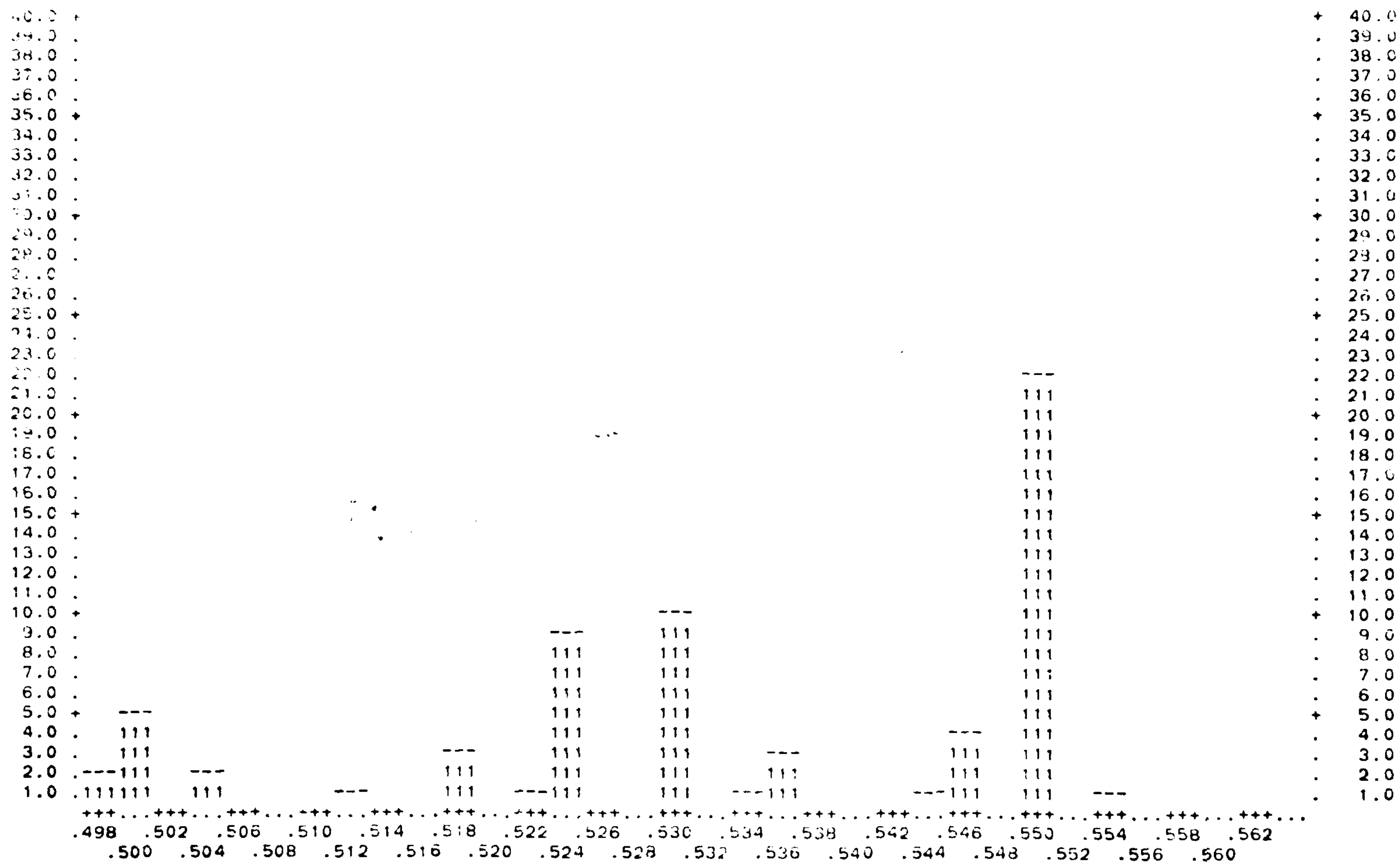


Figure C-12 - Frequency Distribution of the Length of Entrance-Waterline Length Ratio for Twin-Screw Destroyers

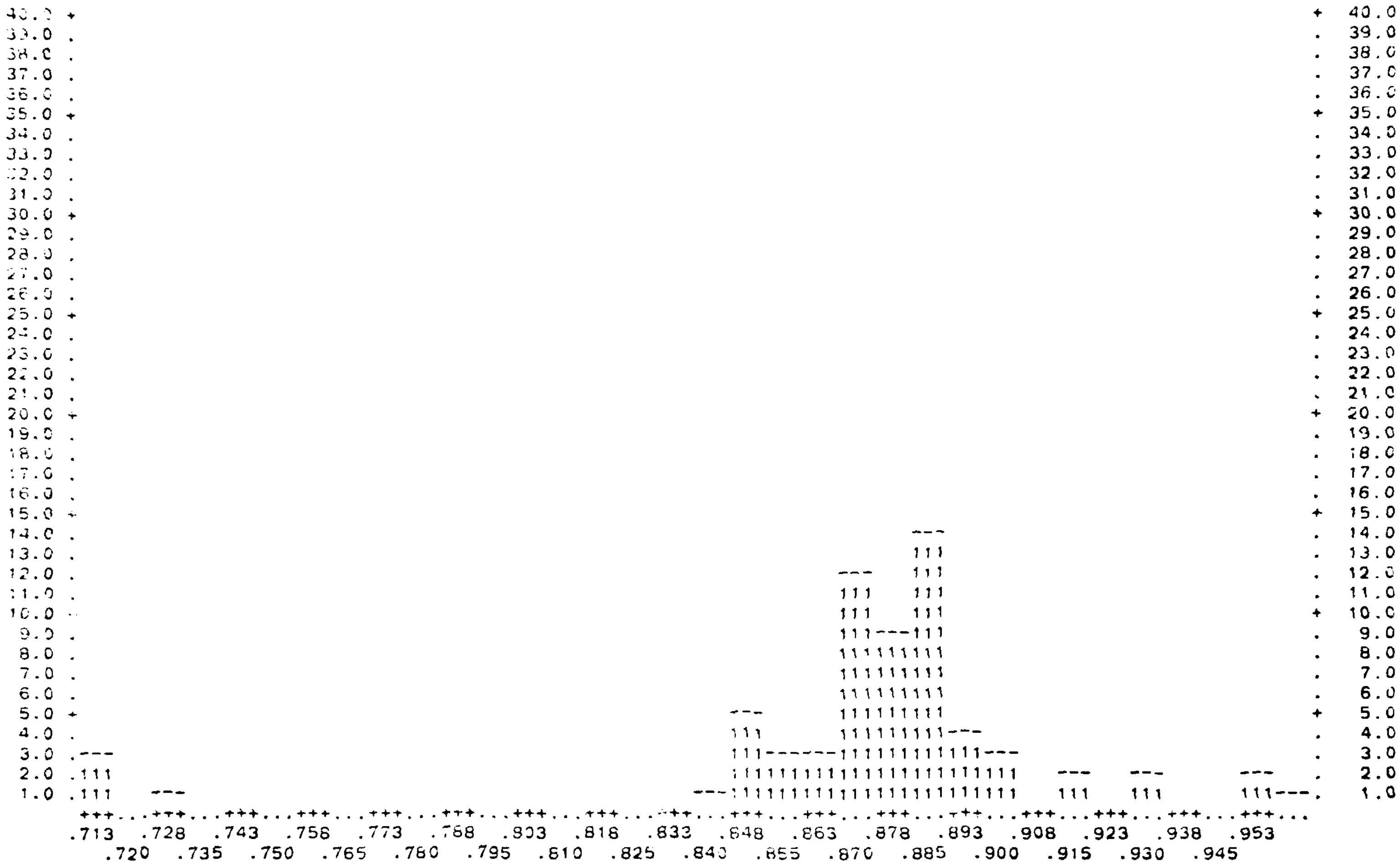


Figure C-13 - Frequency Distribution of the Afterbody Waterplane Coefficient for Twin-Screw Destroyers

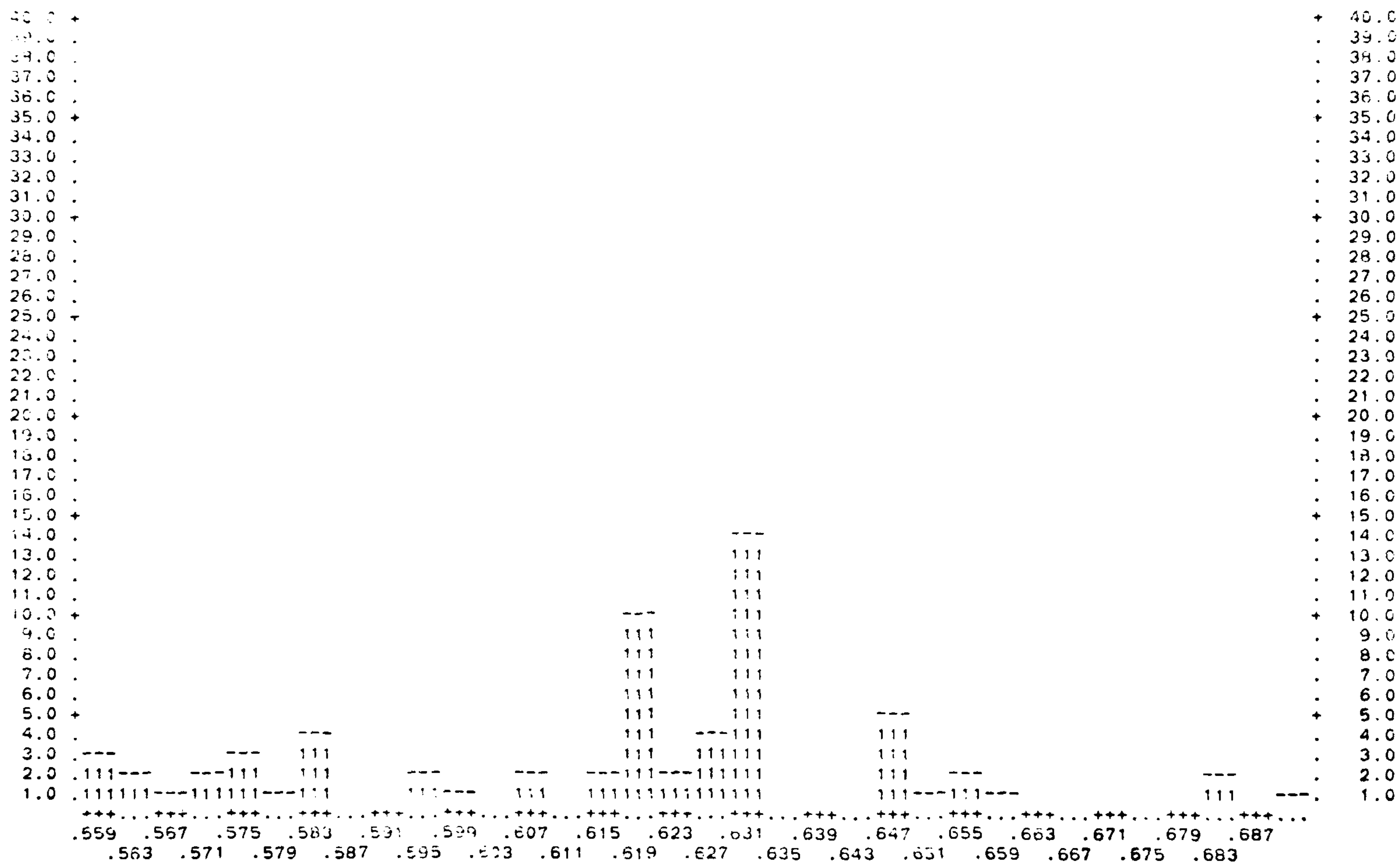


Figure C-14 - Frequency Distribution of the Forebody Waterplane Coefficient for Twin-Screw Destroyers

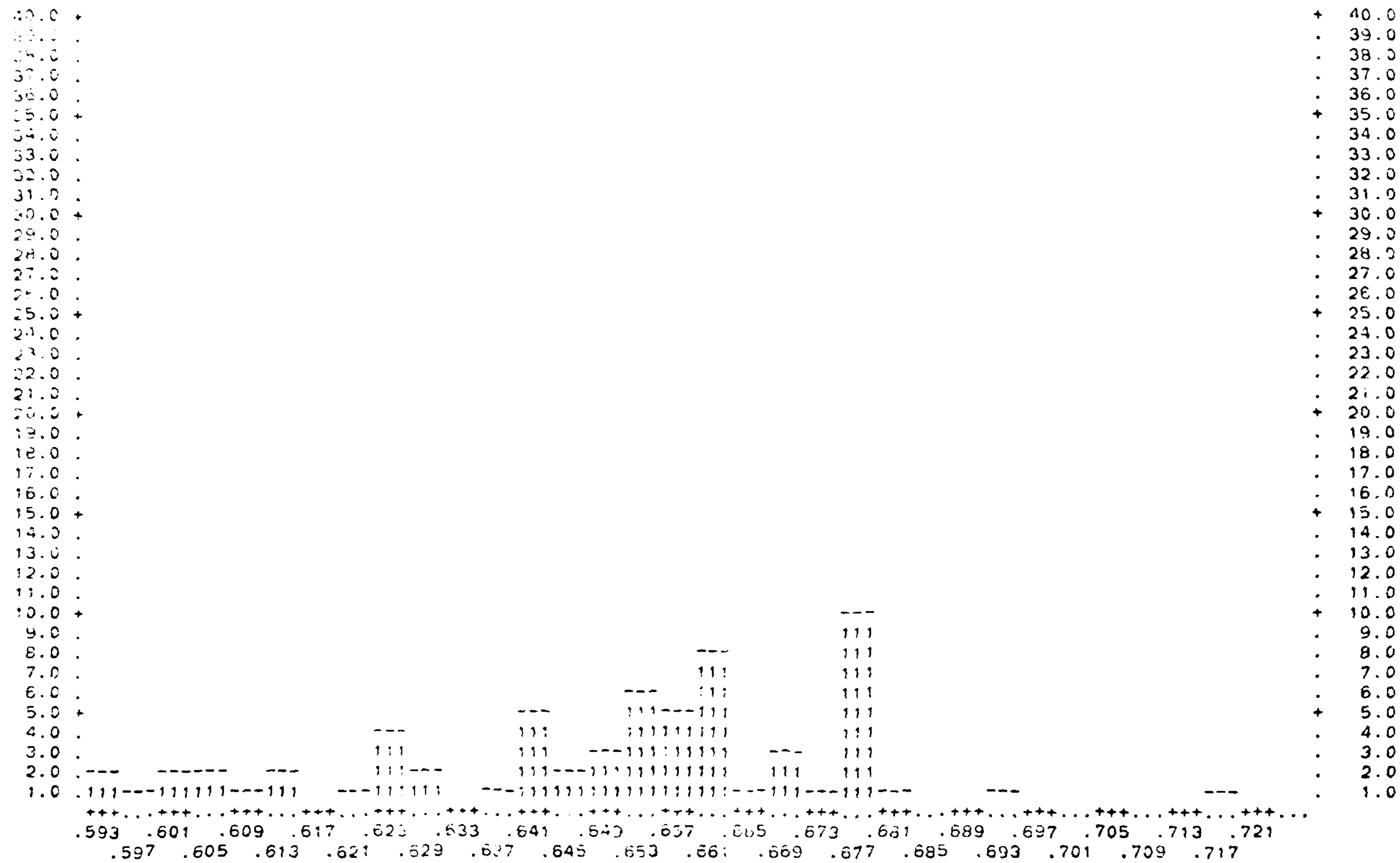


Figure C-15 - Frequency Distribution of the Afterbody Prismatic Coefficient for Twin-Screw Destroyers

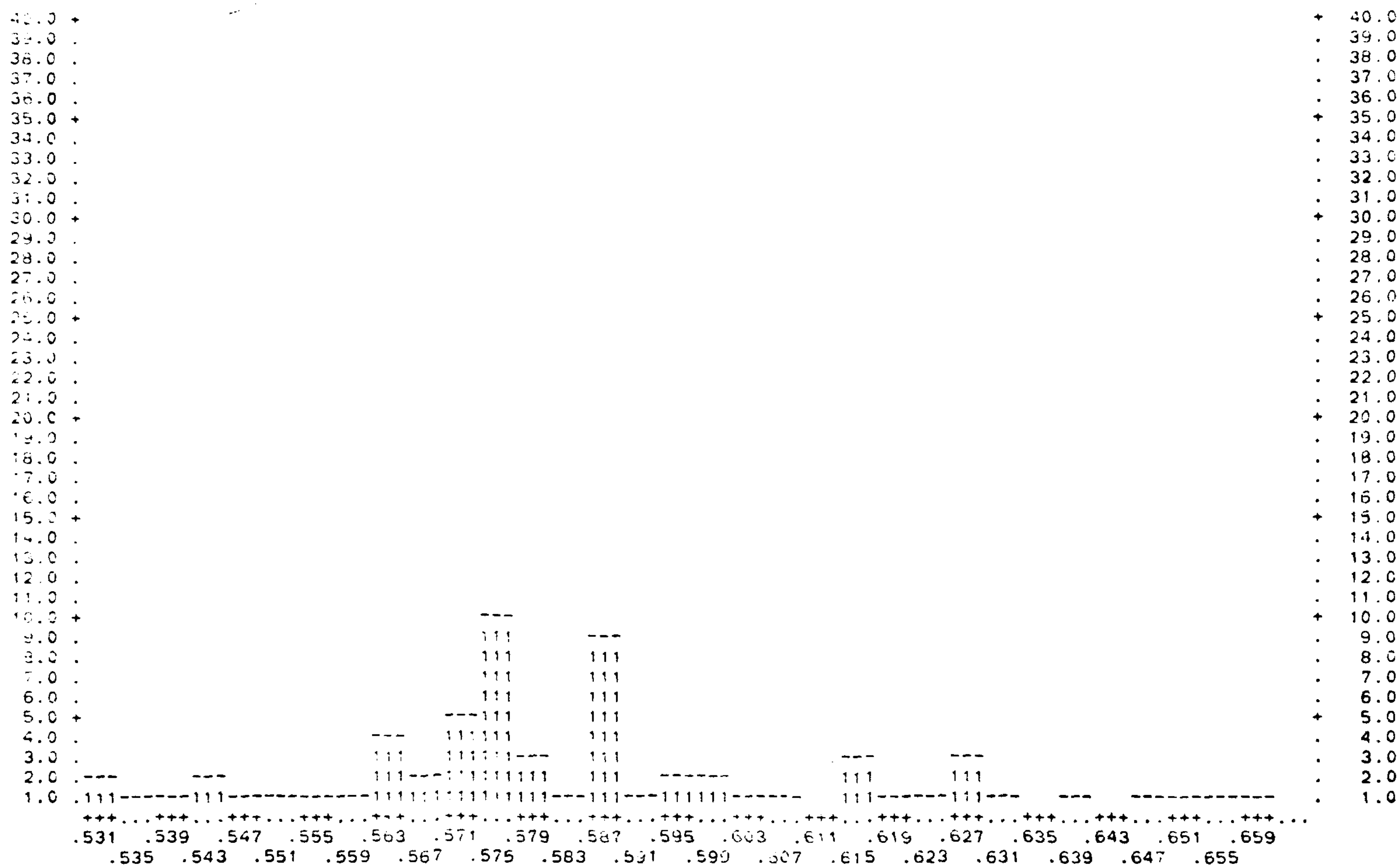


Figure C-16 - Frequency Distribution of the Forebody Prismatic Coefficient for Twin-Screw Destroyers

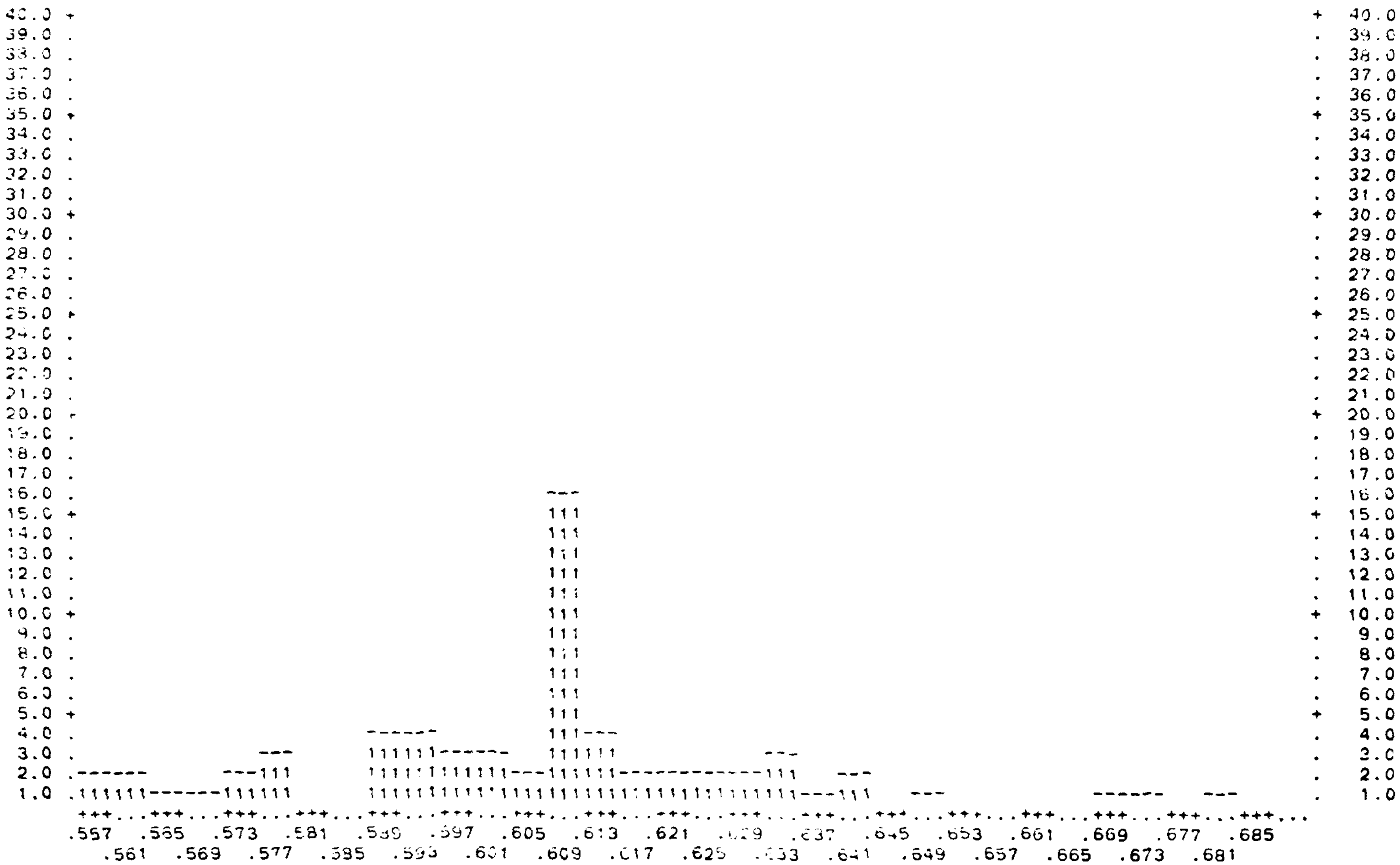


Figure C-17 - Frequency Distribution of the Entrance Prismatic Coefficient for Twin-Screw Destroyers

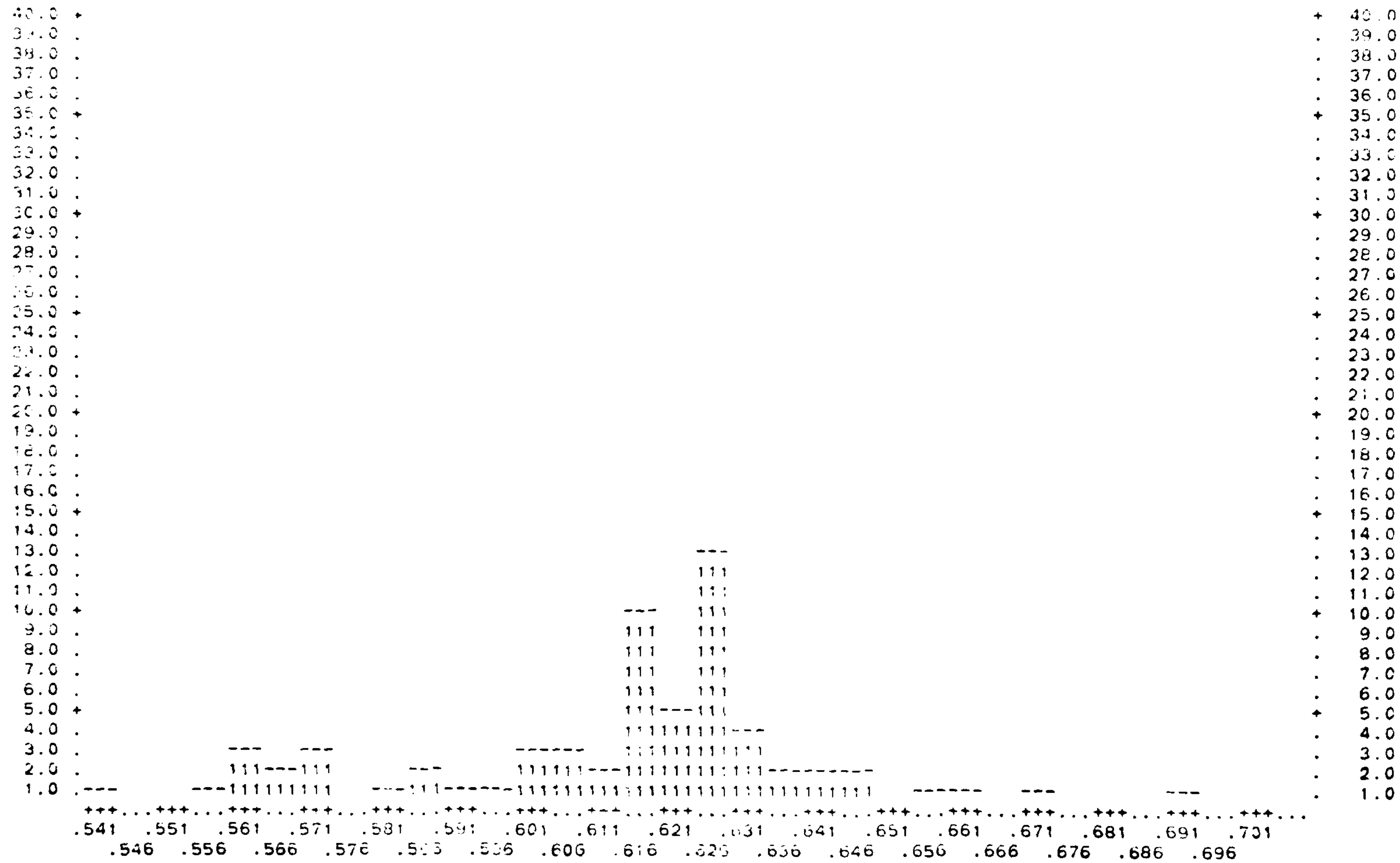


Figure C-18 - Frequency Distribution of the Run Prismatic Coefficient for Twin-Screw Destroyers

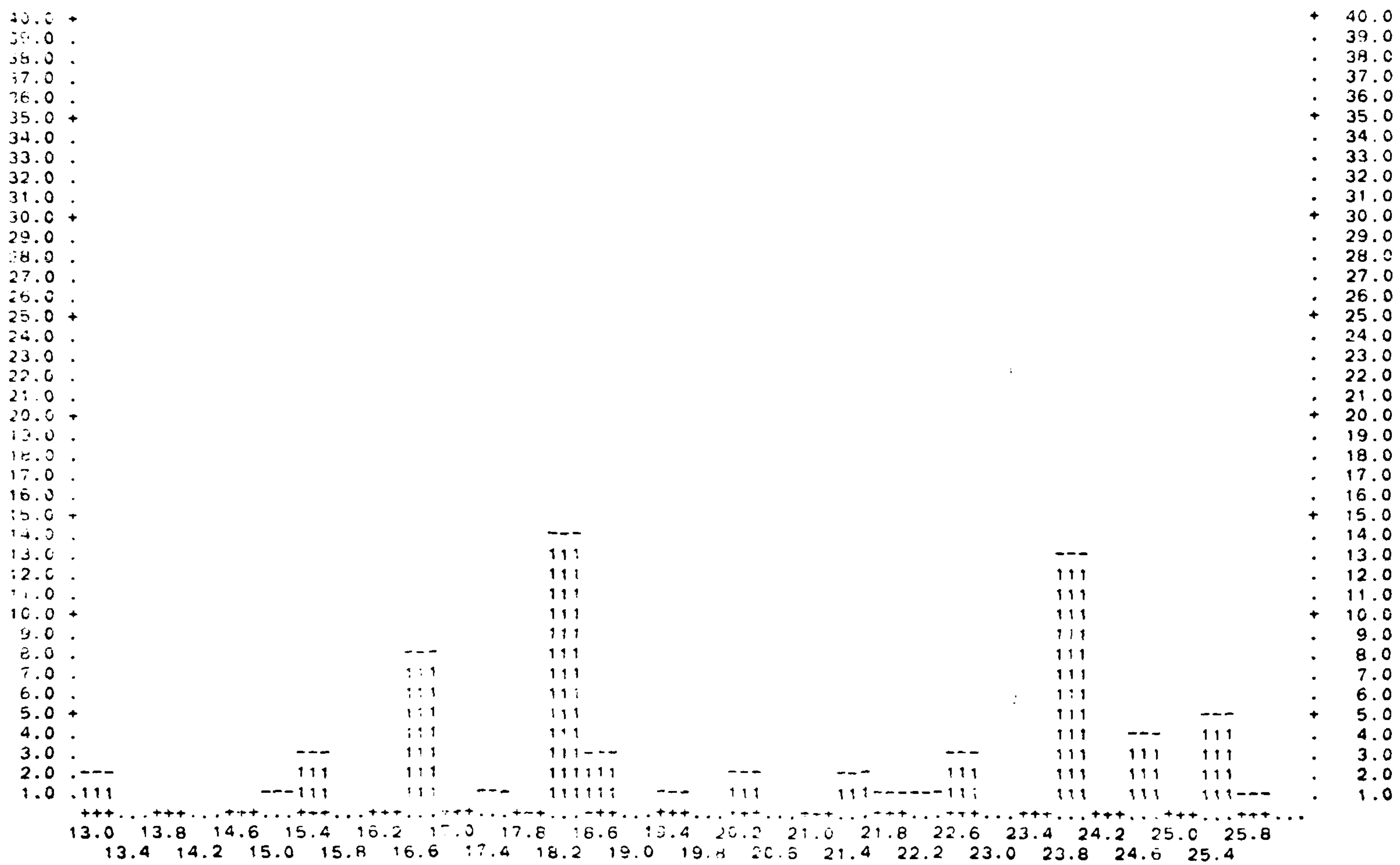


Figure C-19 - Frequency Distribution of the Scale Ratio for Twin-Screw Destroyers

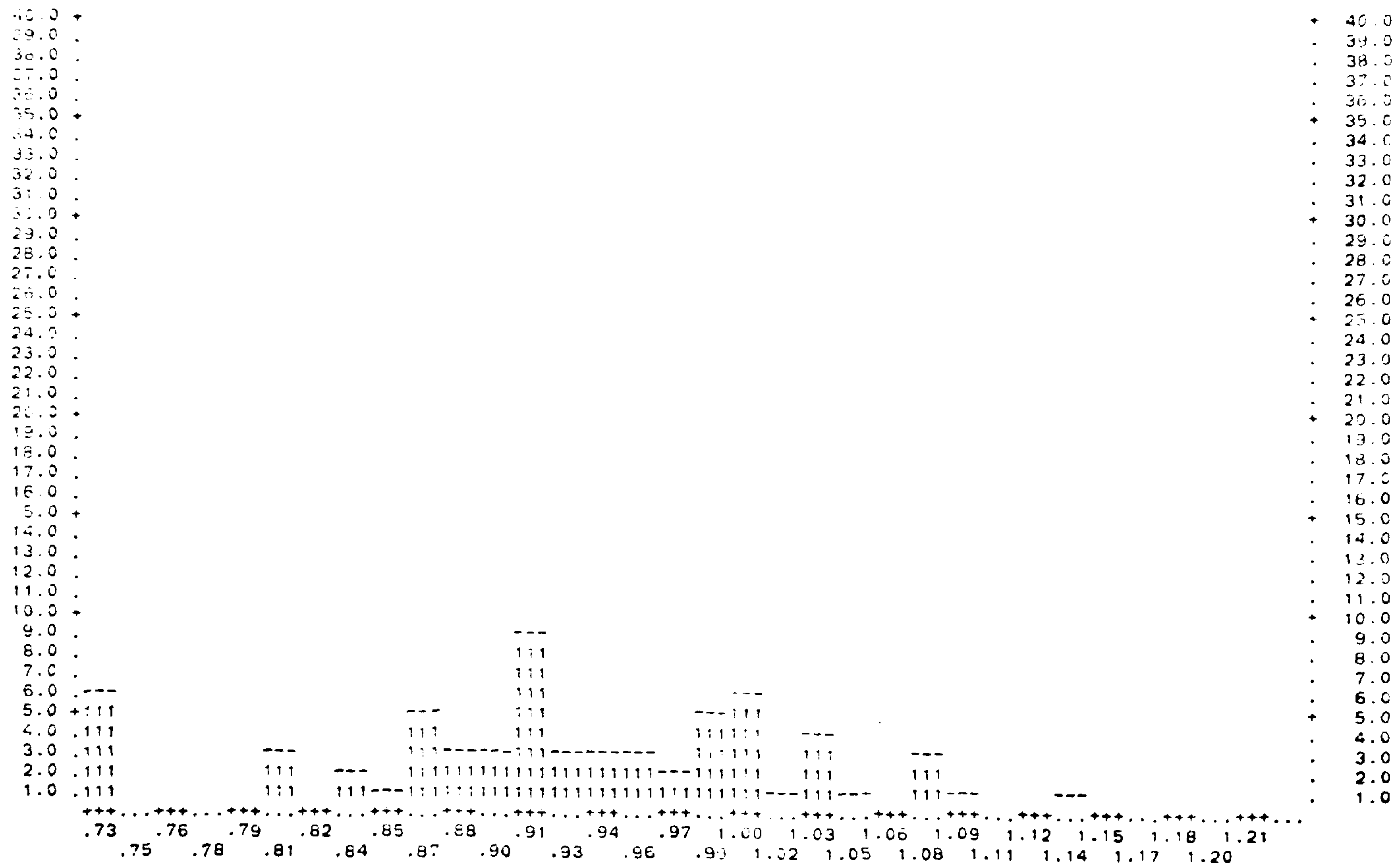


Figure C-20 - Frequency Distribution of the Propeller Diameter-Draft Ratio for Twin-Screw Destroyers

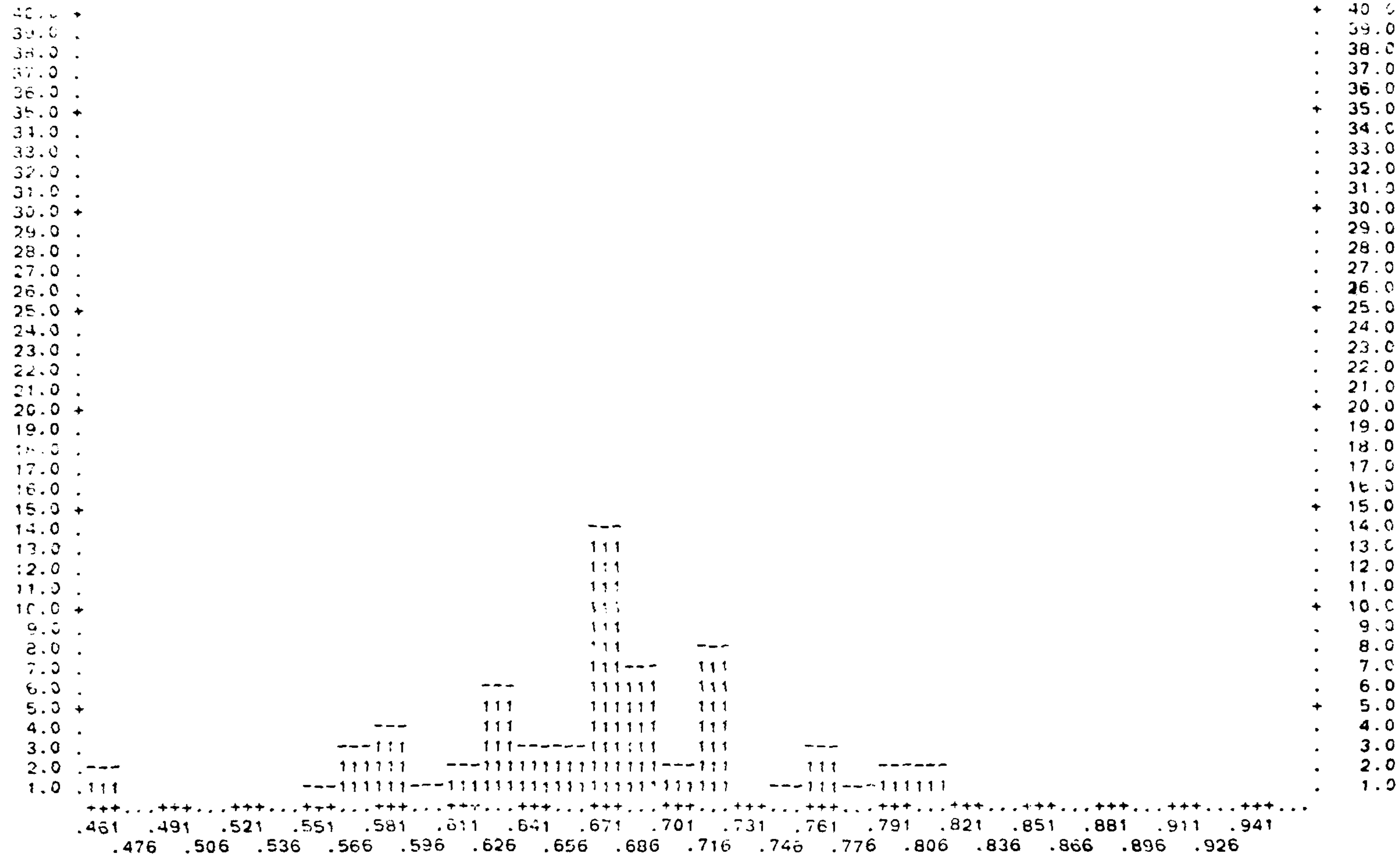


Figure C-21 - Frequency Distribution of the Projected Area-Disk Area Ratio for Twin-Screw Destroyers

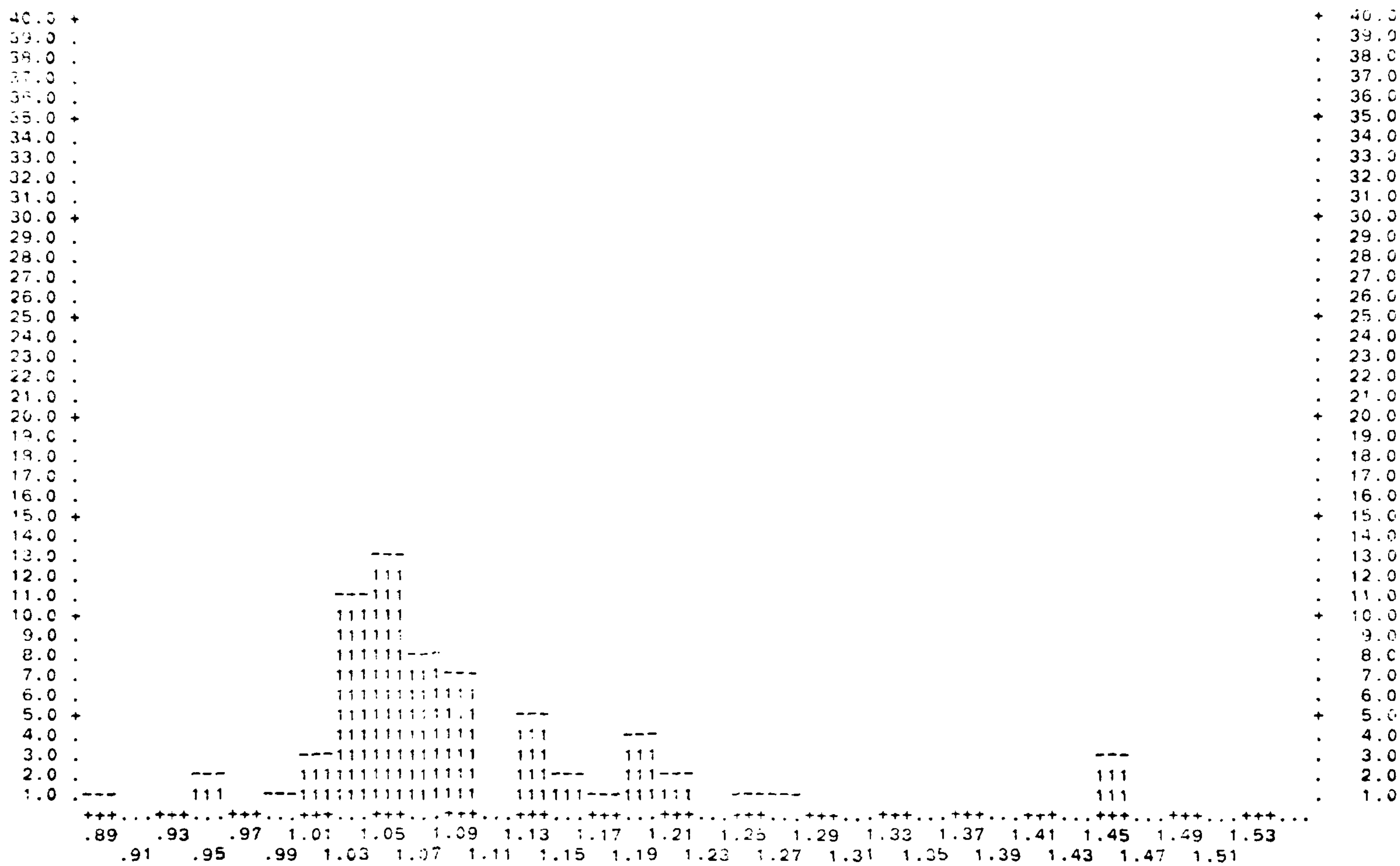


Figure C-22 - Frequency Distribution of the Pitch Ratio for Twin-Screw Destroyers

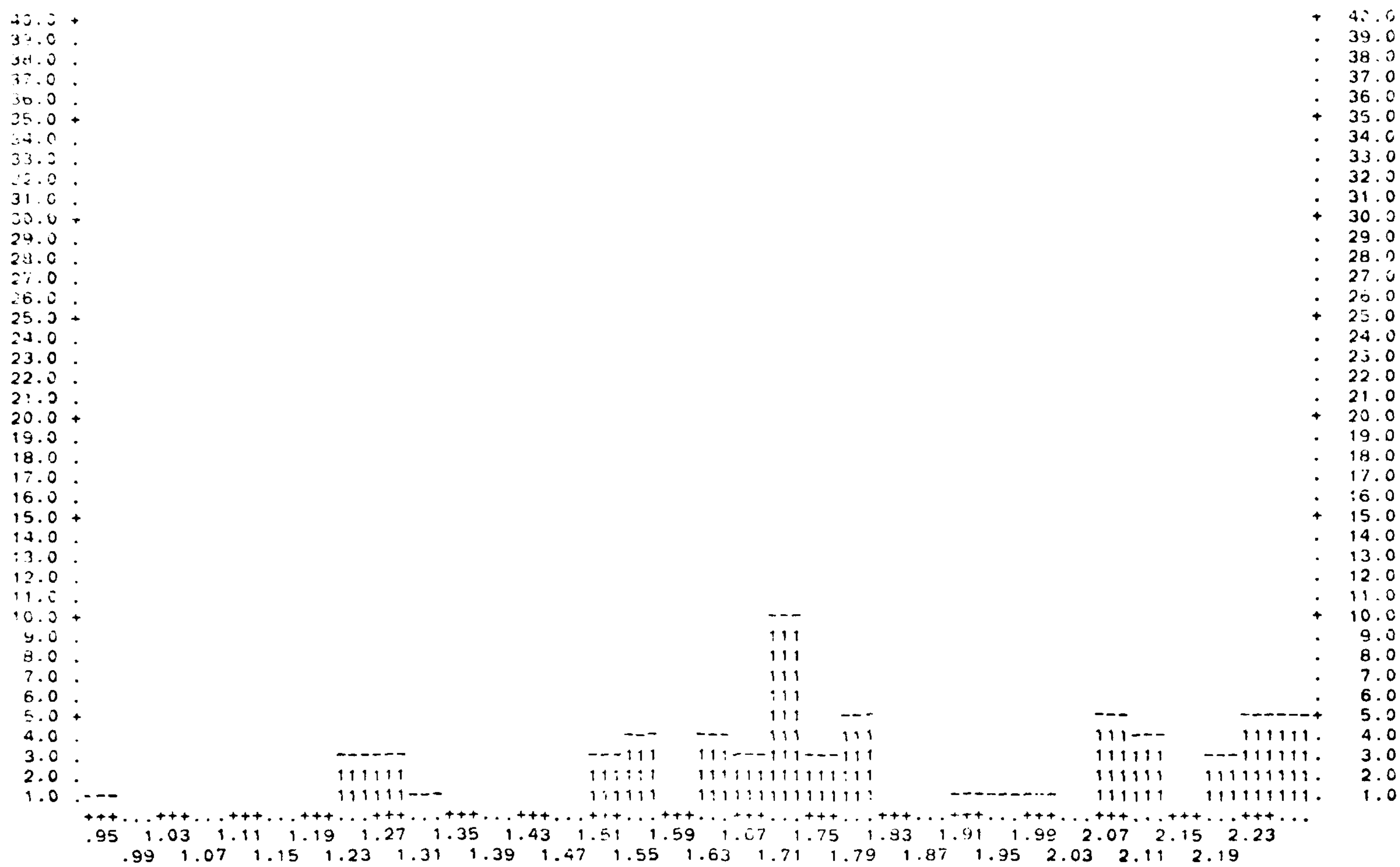


Figure C-23 - Frequency Distribution of the Ship Reynolds Number for Twin-Screw Destroyers

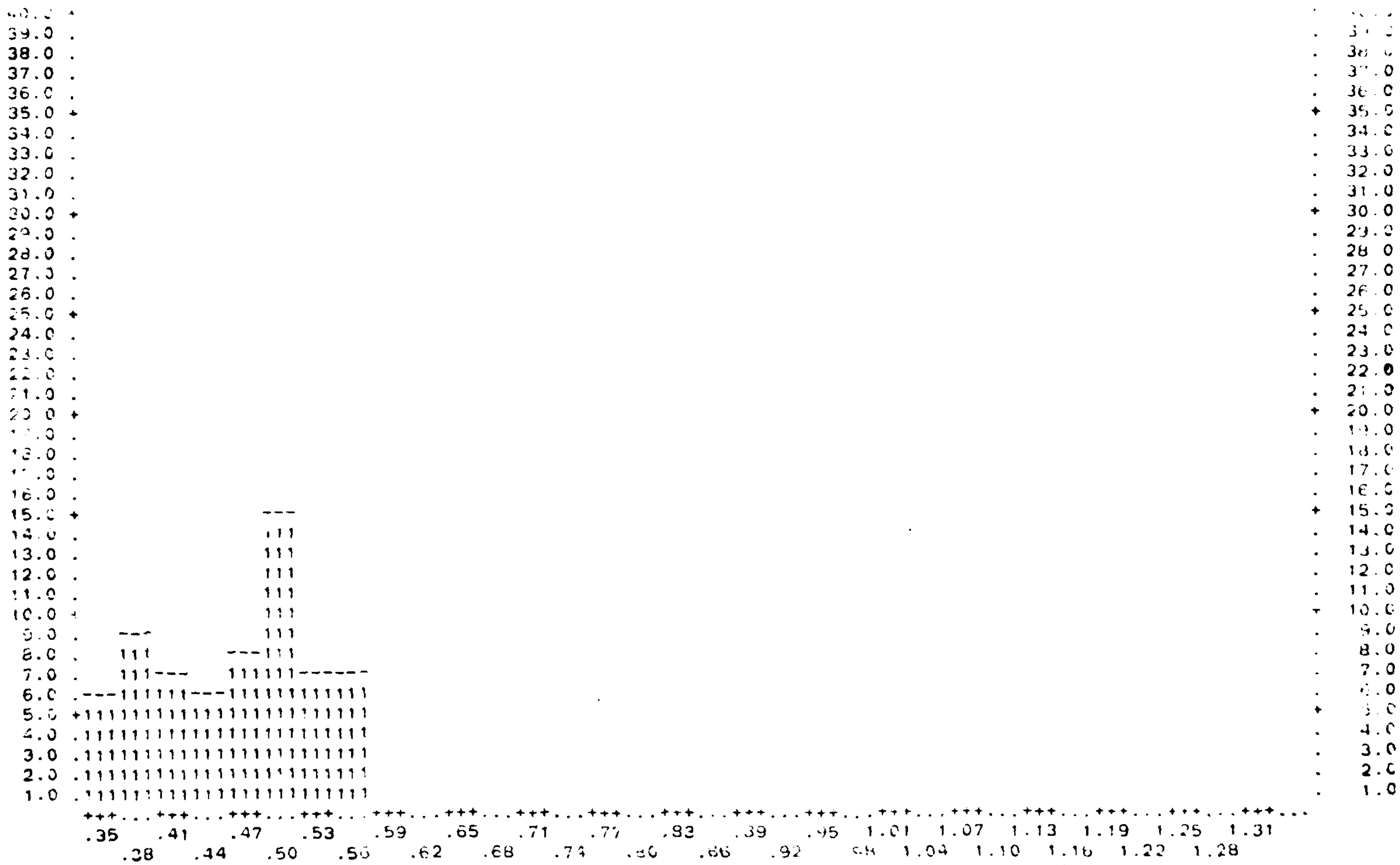


Figure C-24 - Frequency Distribution of the Design Froude Number for Twin-Screw Destroyers

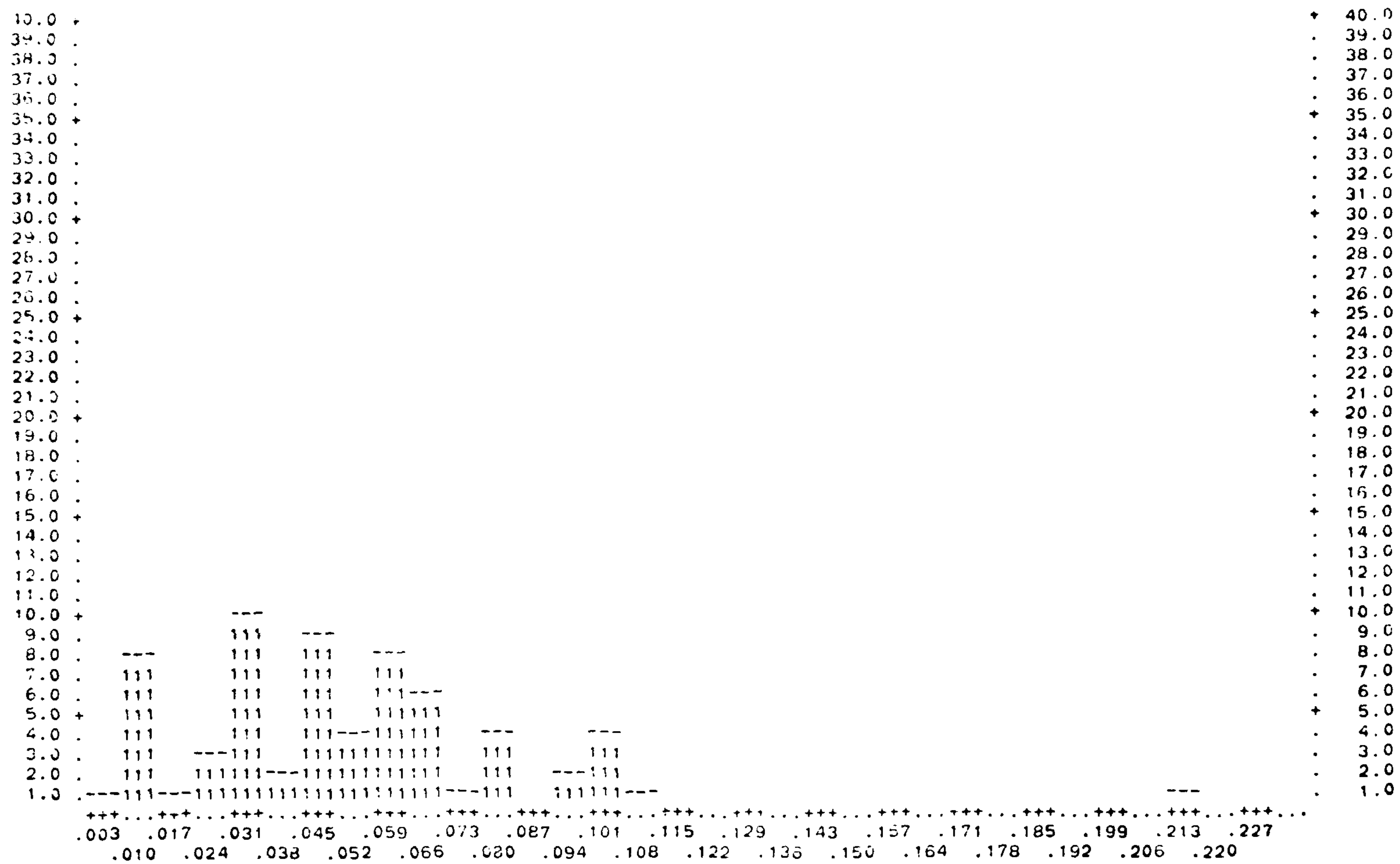


Figure C-25 - Frequency Distribution of the Thrust-Deduction Fraction for Twin-Screw Destroyers

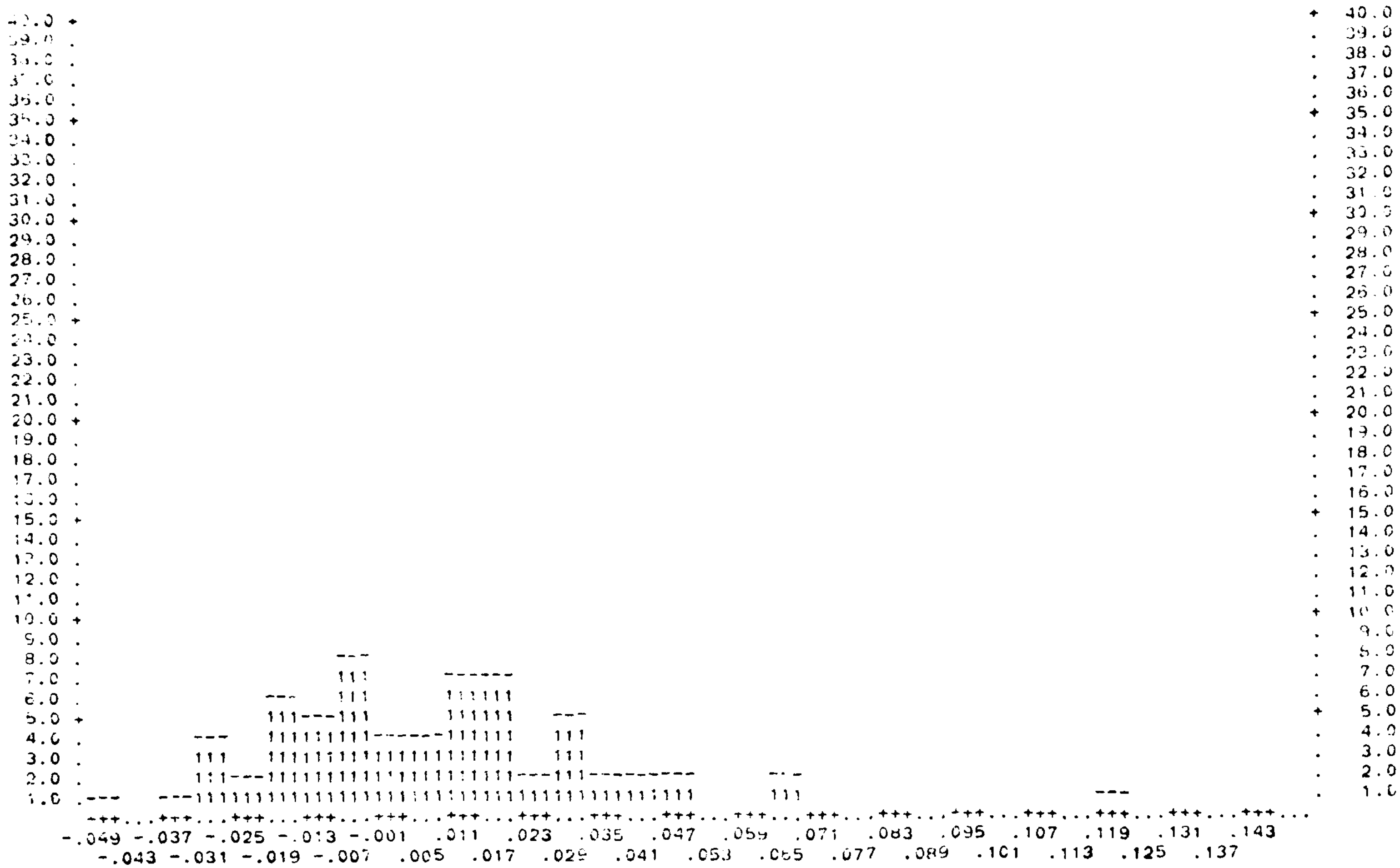


Figure C-26 - Frequency Distribution of the Thrust-Wake Fraction for Twin-Screw Destroyers

APPENDIX D

VARIATION OF INDEPENDENT VARIABLES WITH THRUST-DEDUCTION AND THRUST-WAKE FRACTIONS

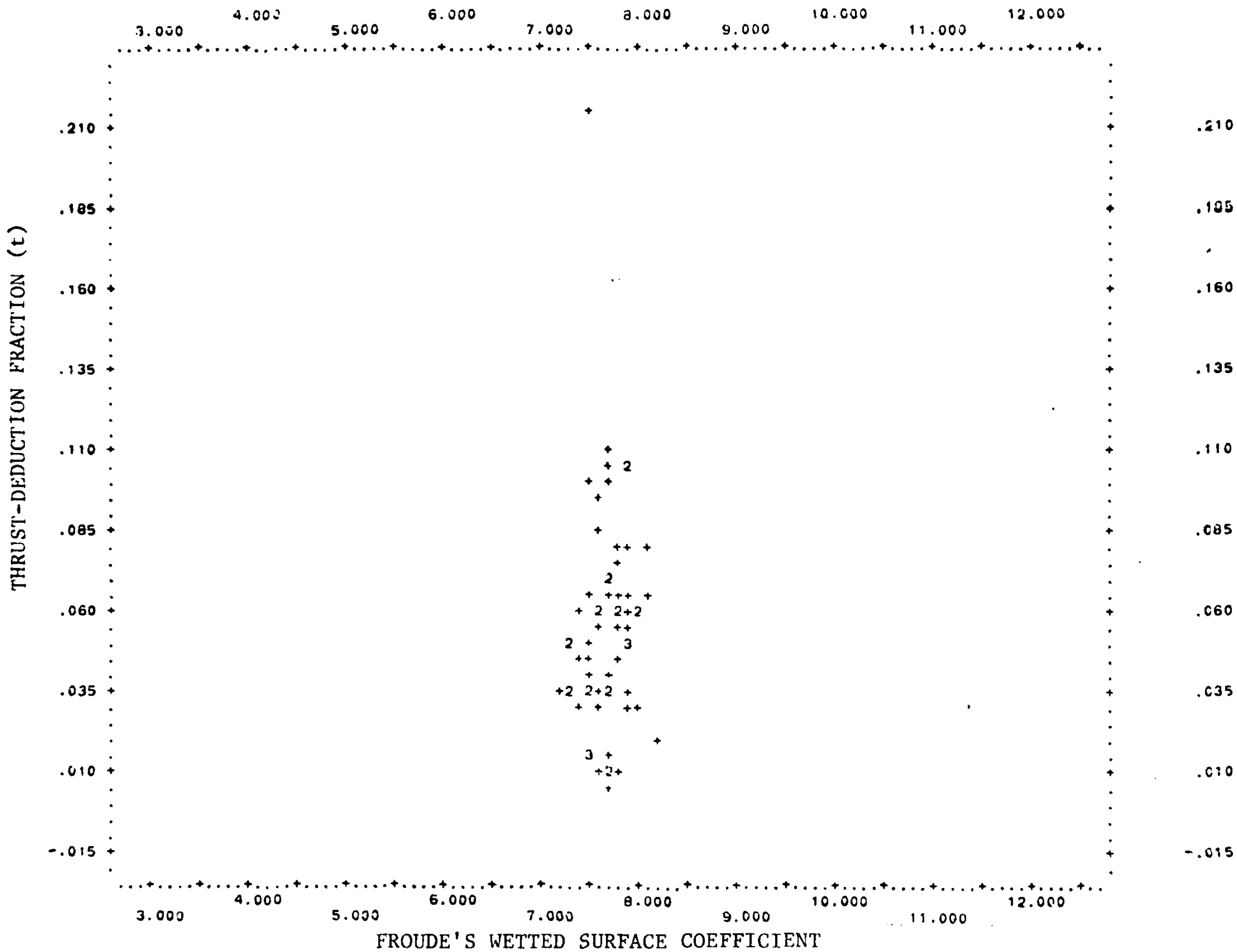


Figure D-1 - Variation of Froude's Wetted Surface Coefficient and Thrust-Deduction Fraction

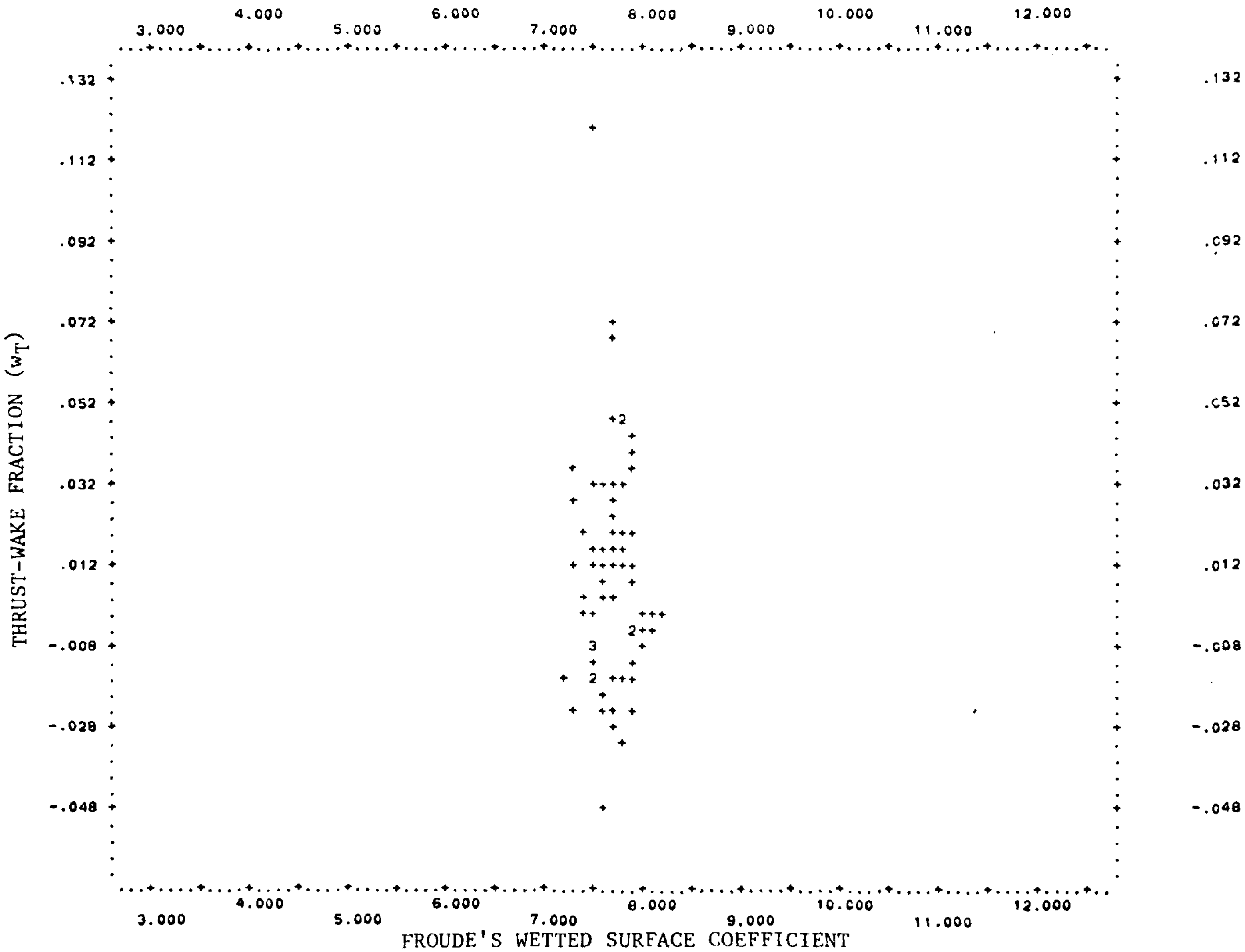


Figure D-2 - Variation of Froude's Wetted Surface Coefficient and Thrust-Wake Fraction

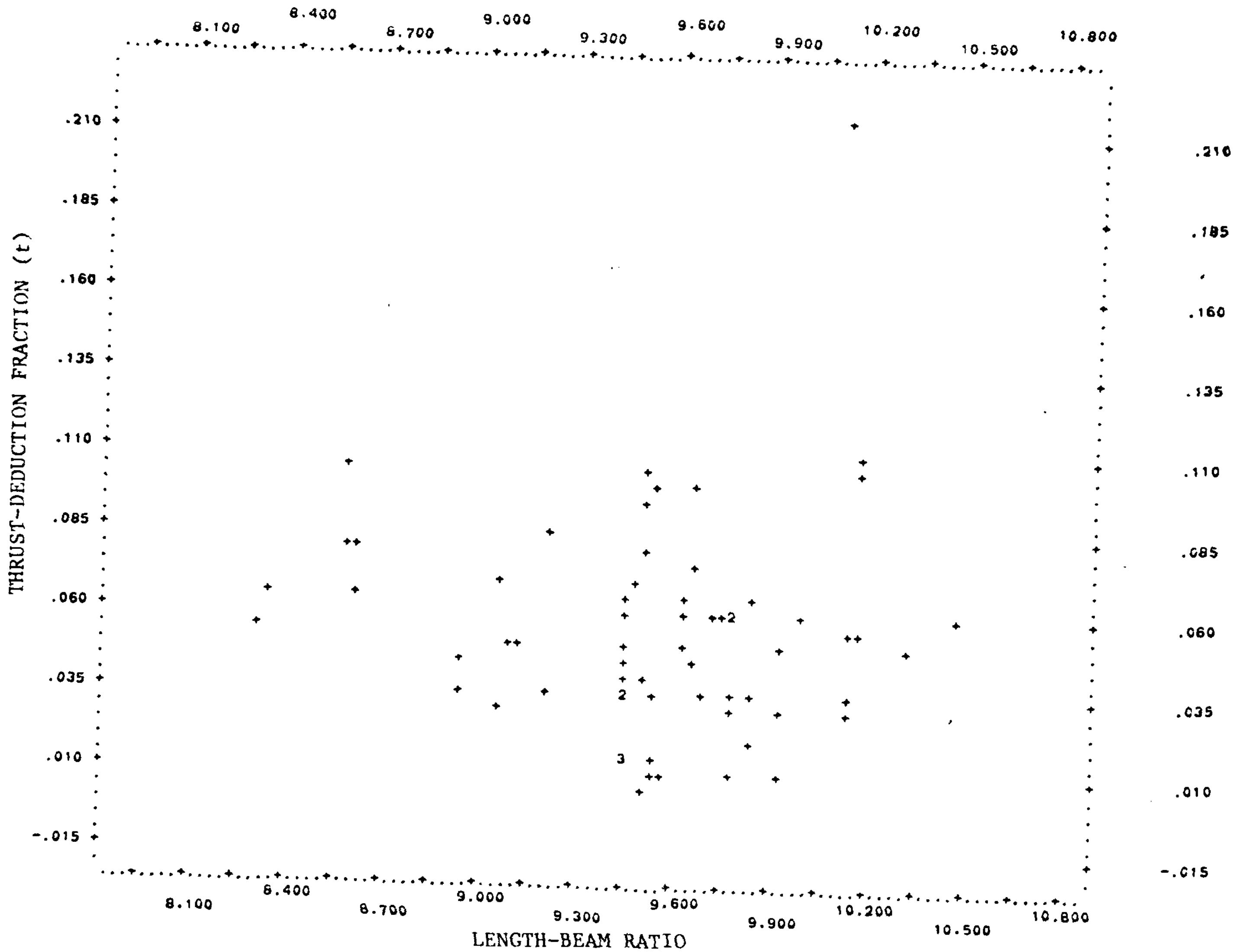


Figure D-3 - Variation of Length-Beam Ratio and Thrust-Deduction Fraction

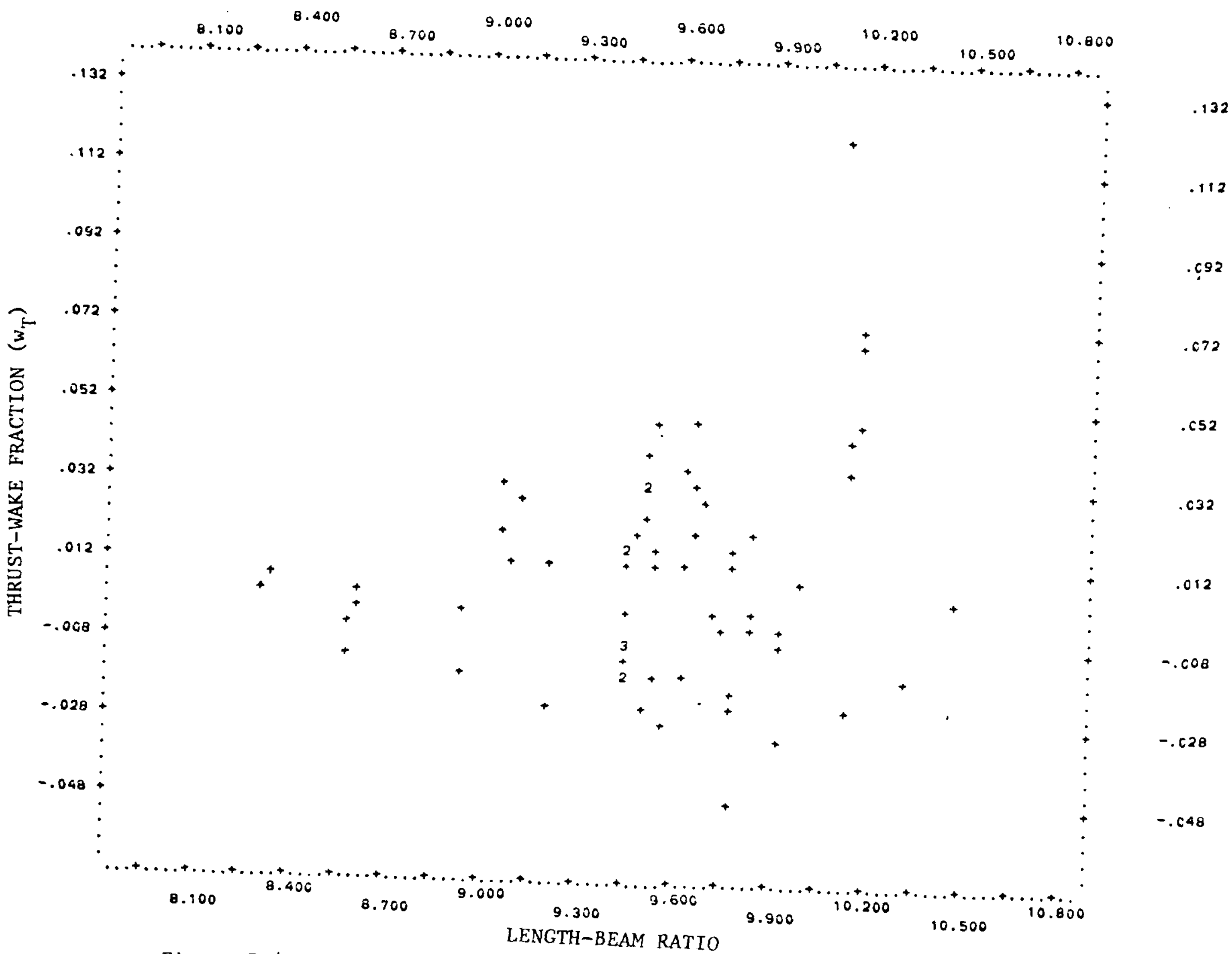


Figure D-4 - Variation of Length-Beam Ratio and Thrust-Wake Fraction

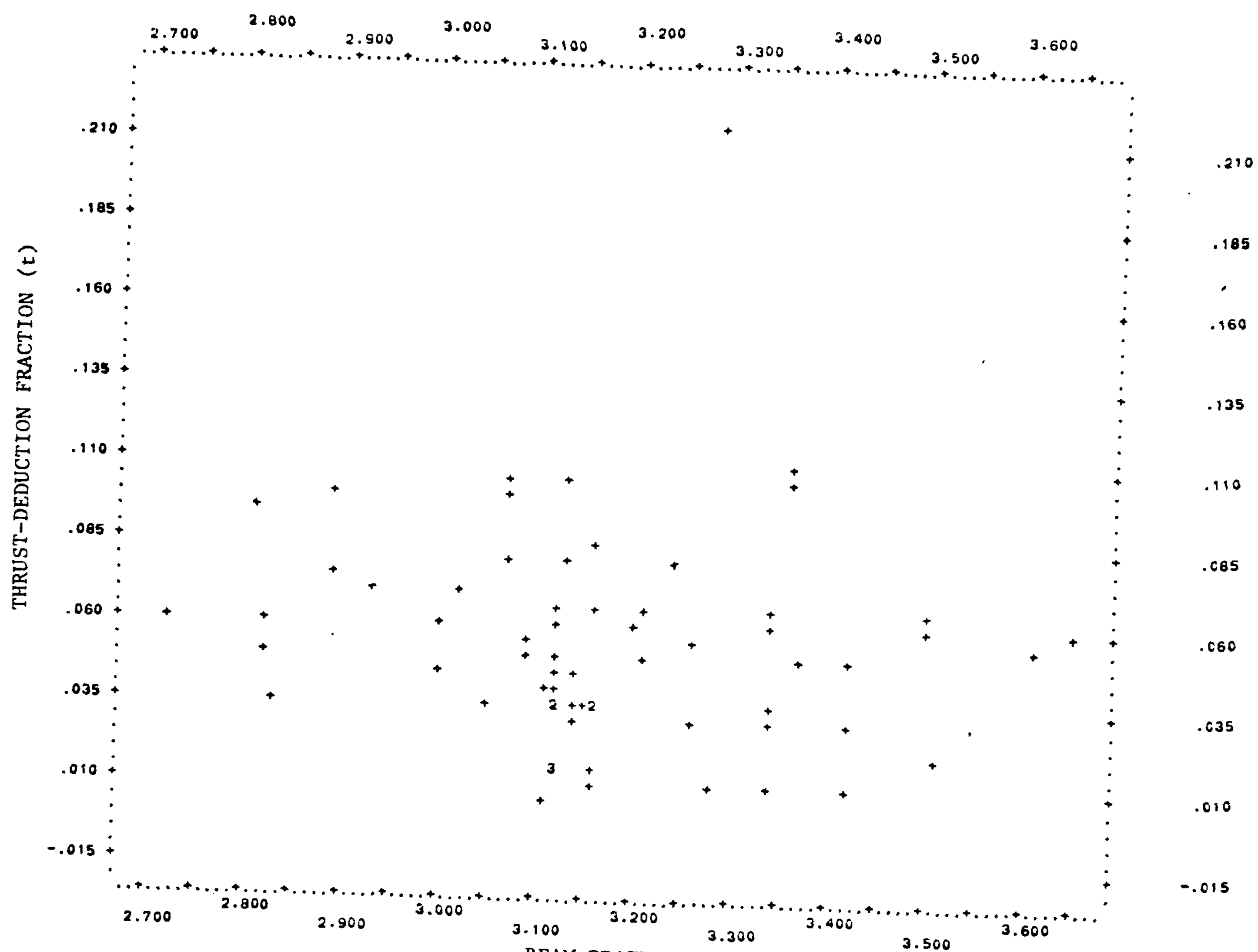


Figure D-5 - Variation of Beam-Draft Ratio and Thrust-Deduction Fraction

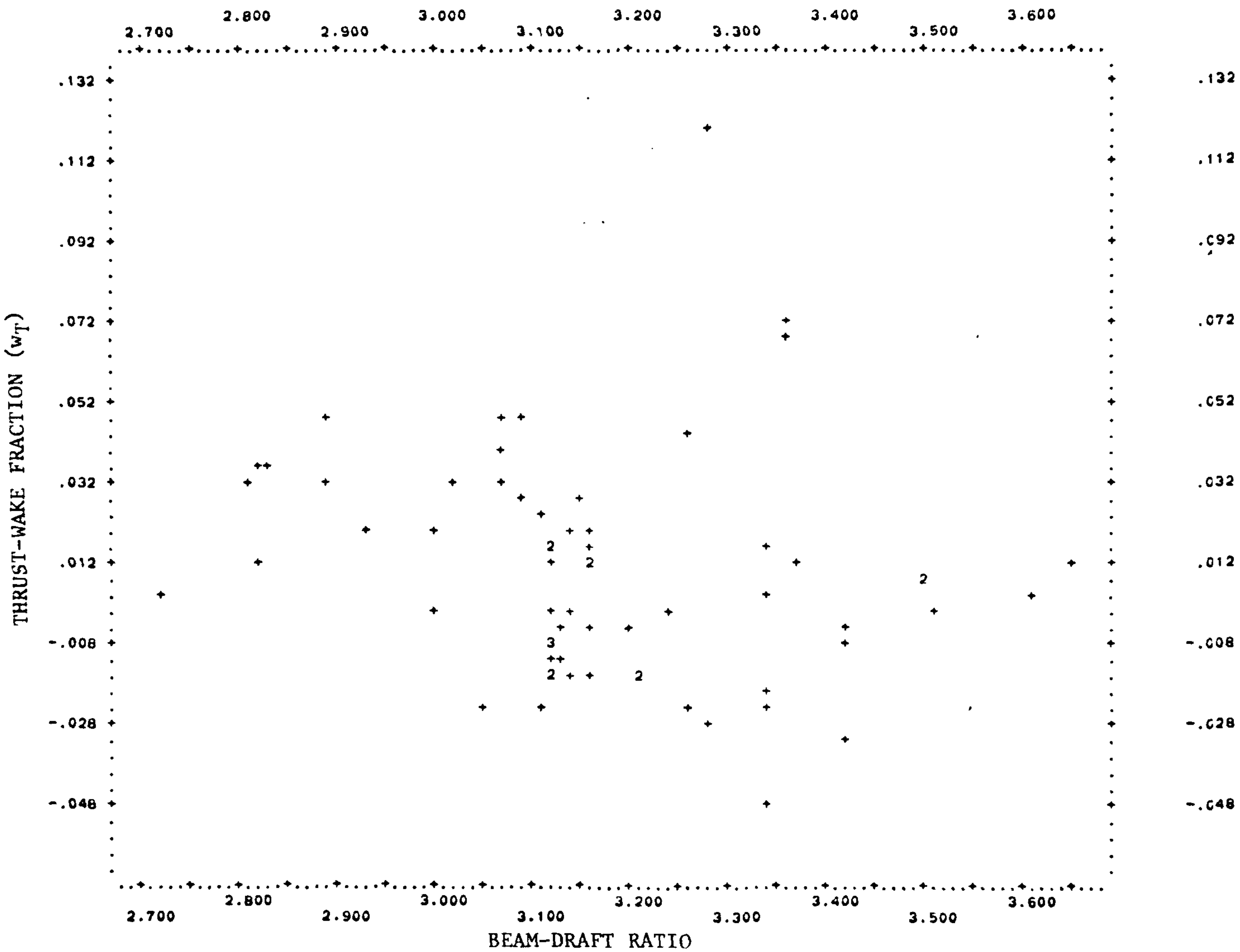


Figure D-6 - Variation of Beam-Draft Ratio and Thrust-Wake Fraction

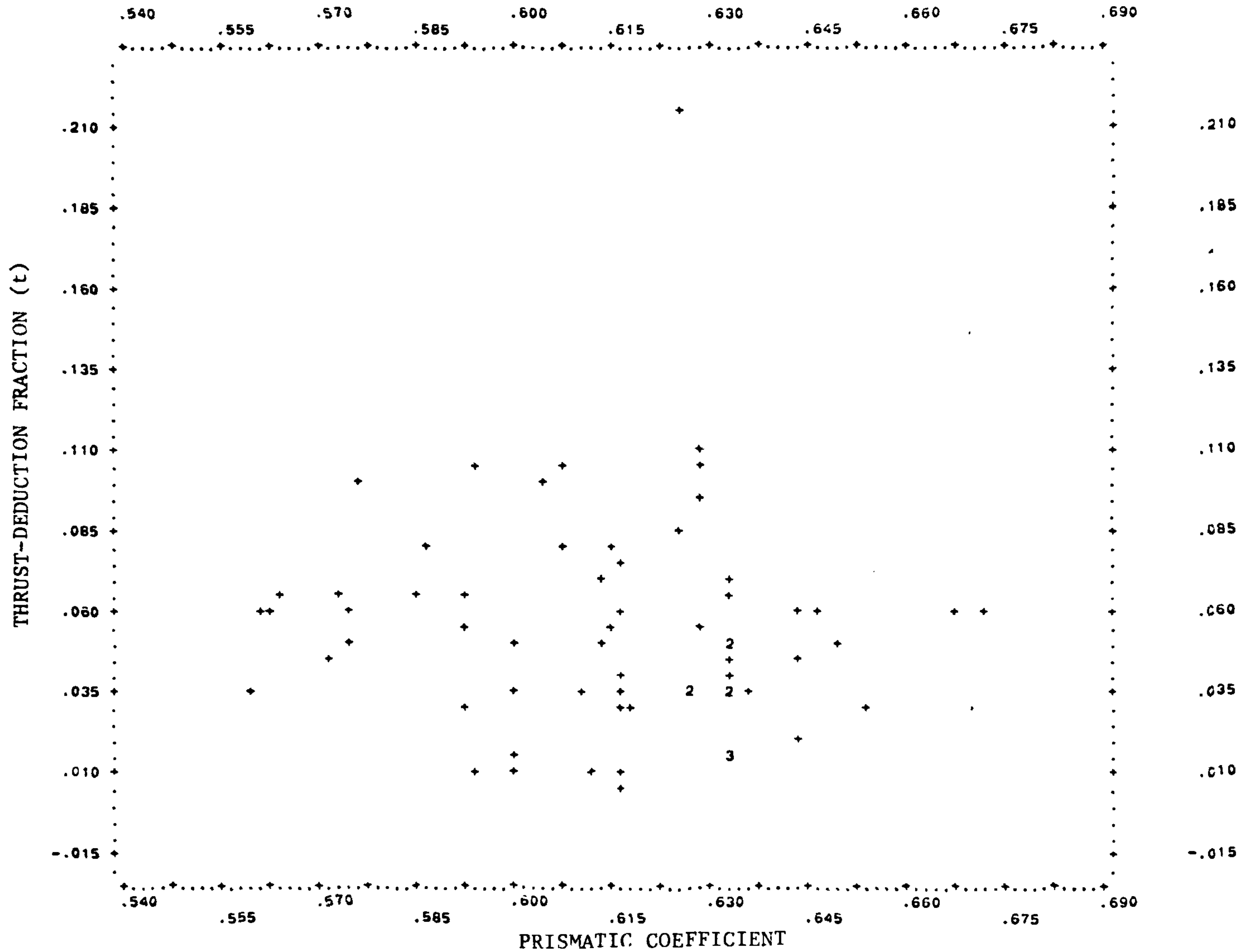


Figure D-7 - Variation of Prismatic Coefficient and Thrust-Deduction Fraction

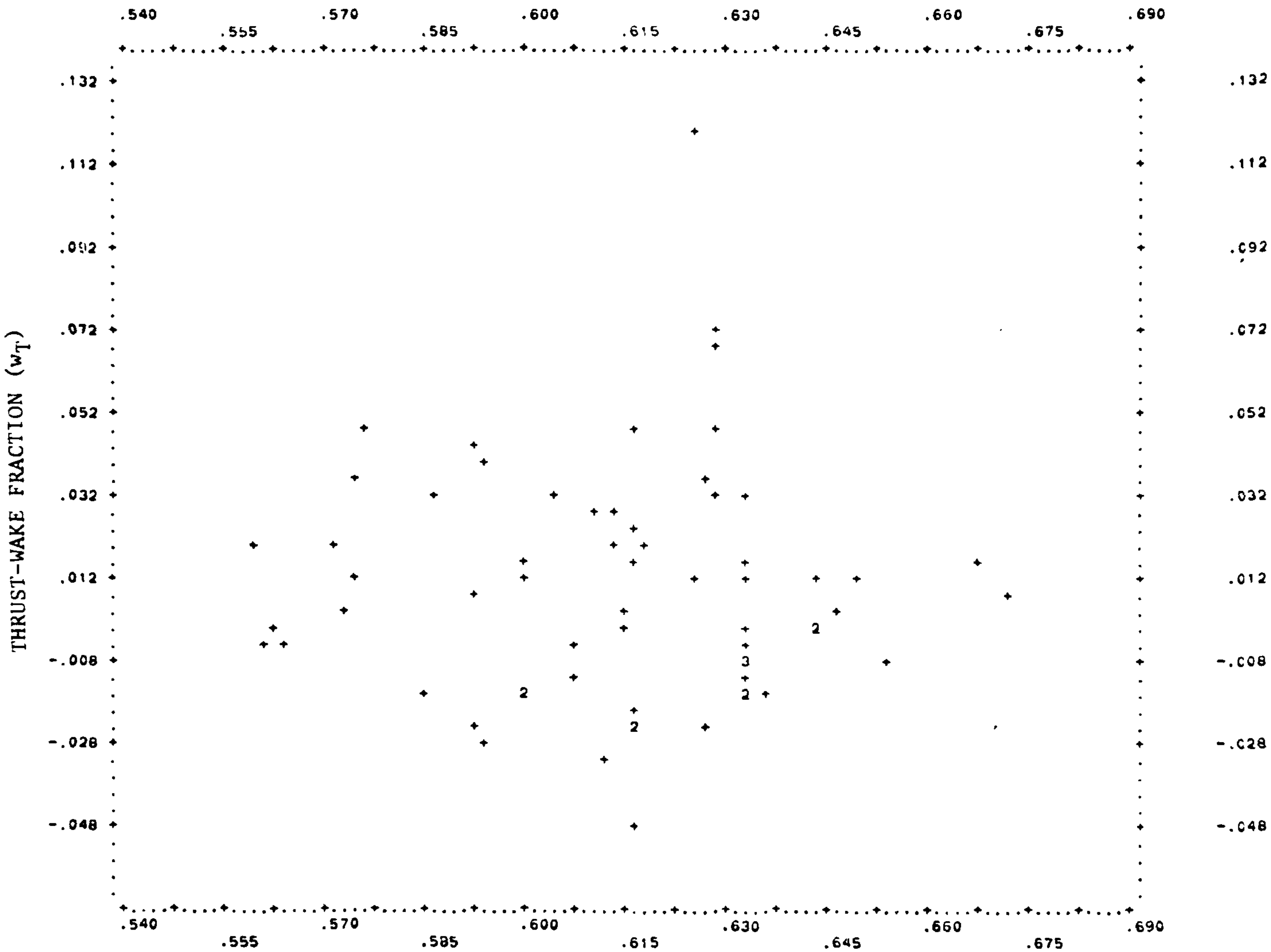


Figure D-8 - Variation of Prismatic Coefficient and Thrust-Wake Fraction

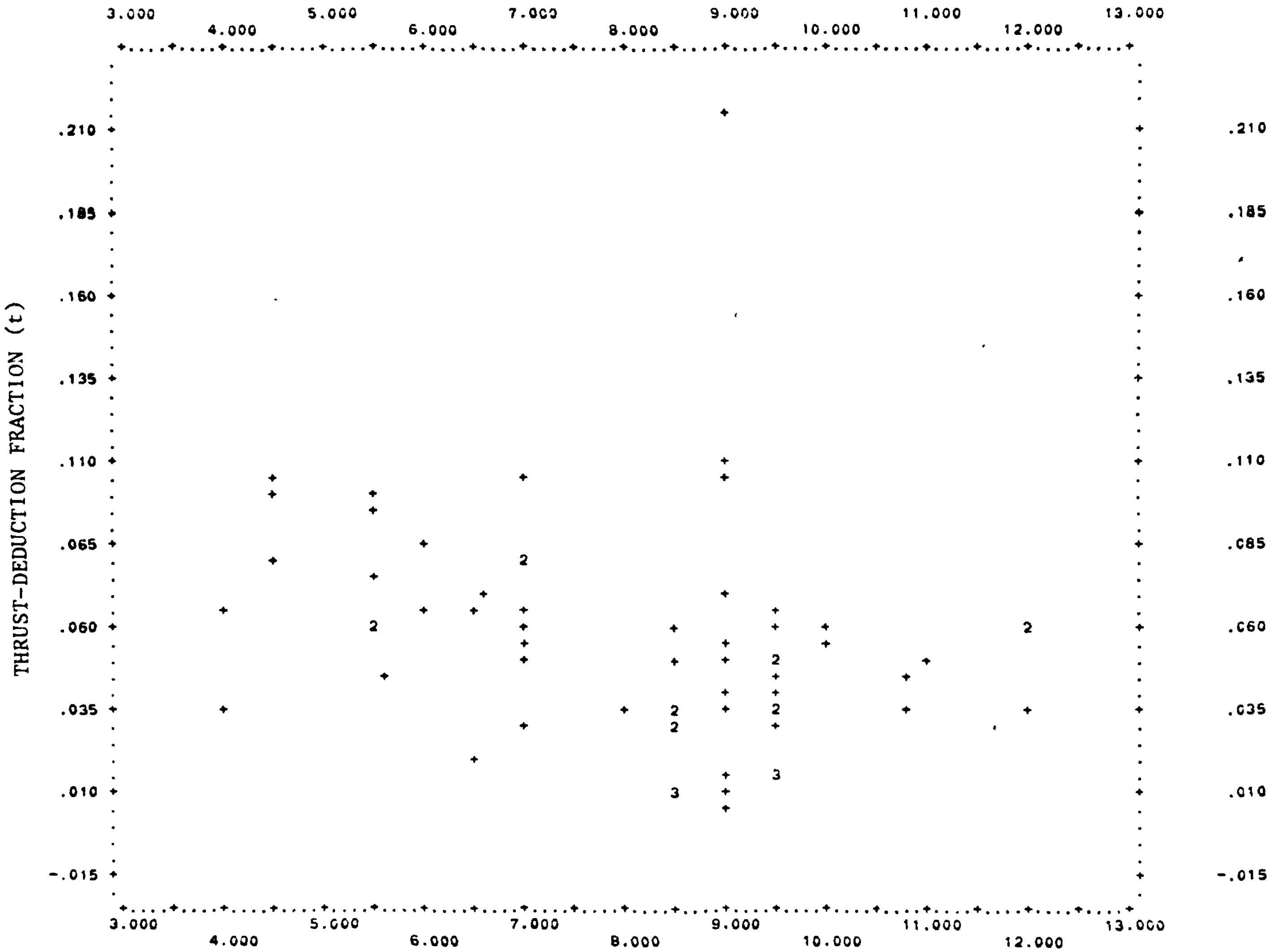


Figure D-9 - Variation of Half Angle of Entrance and Thrust-Deduction Fraction

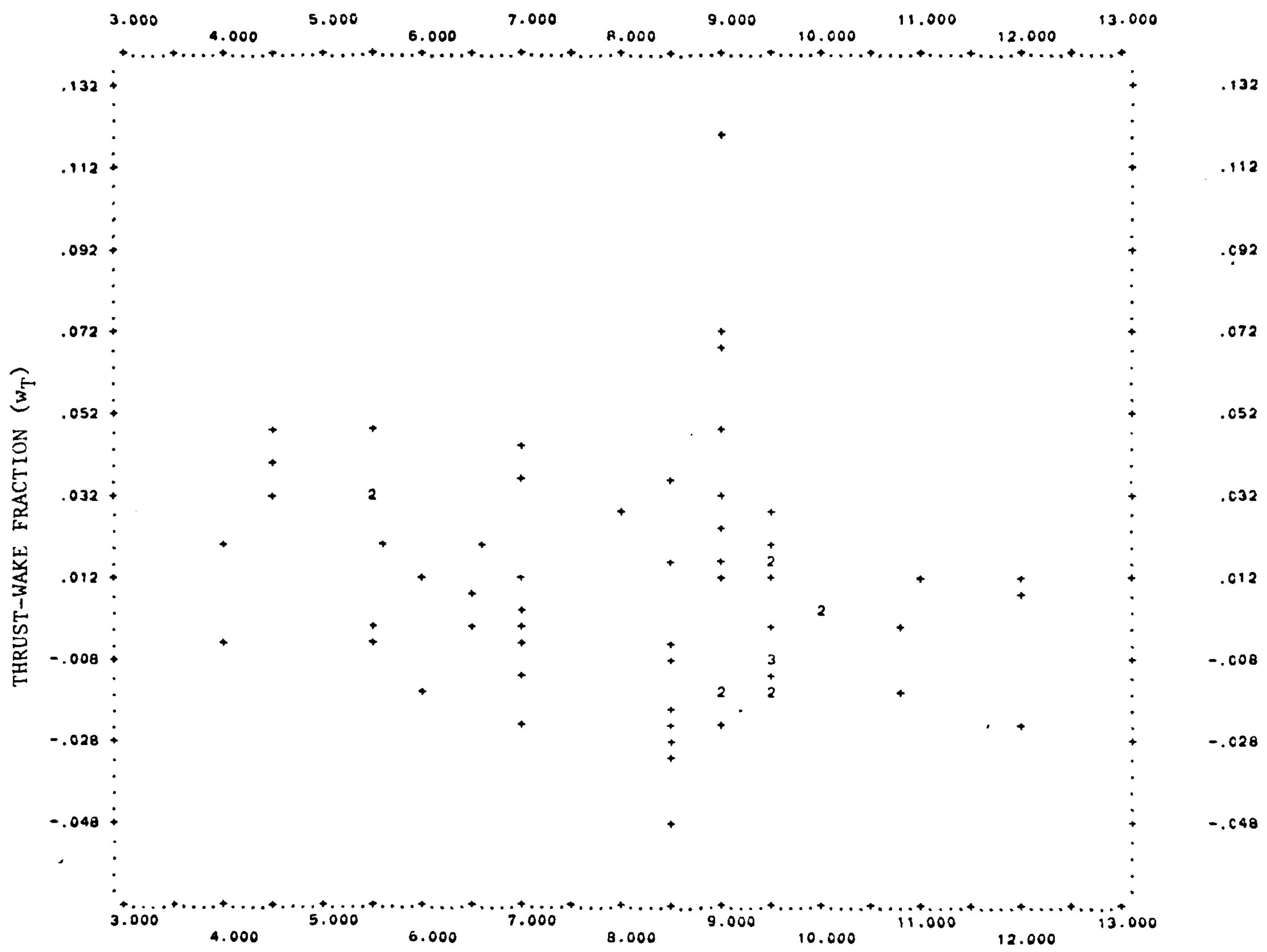


Figure D-10 - Variation of Half Angle of Entrance and Thrust-Wake Fraction

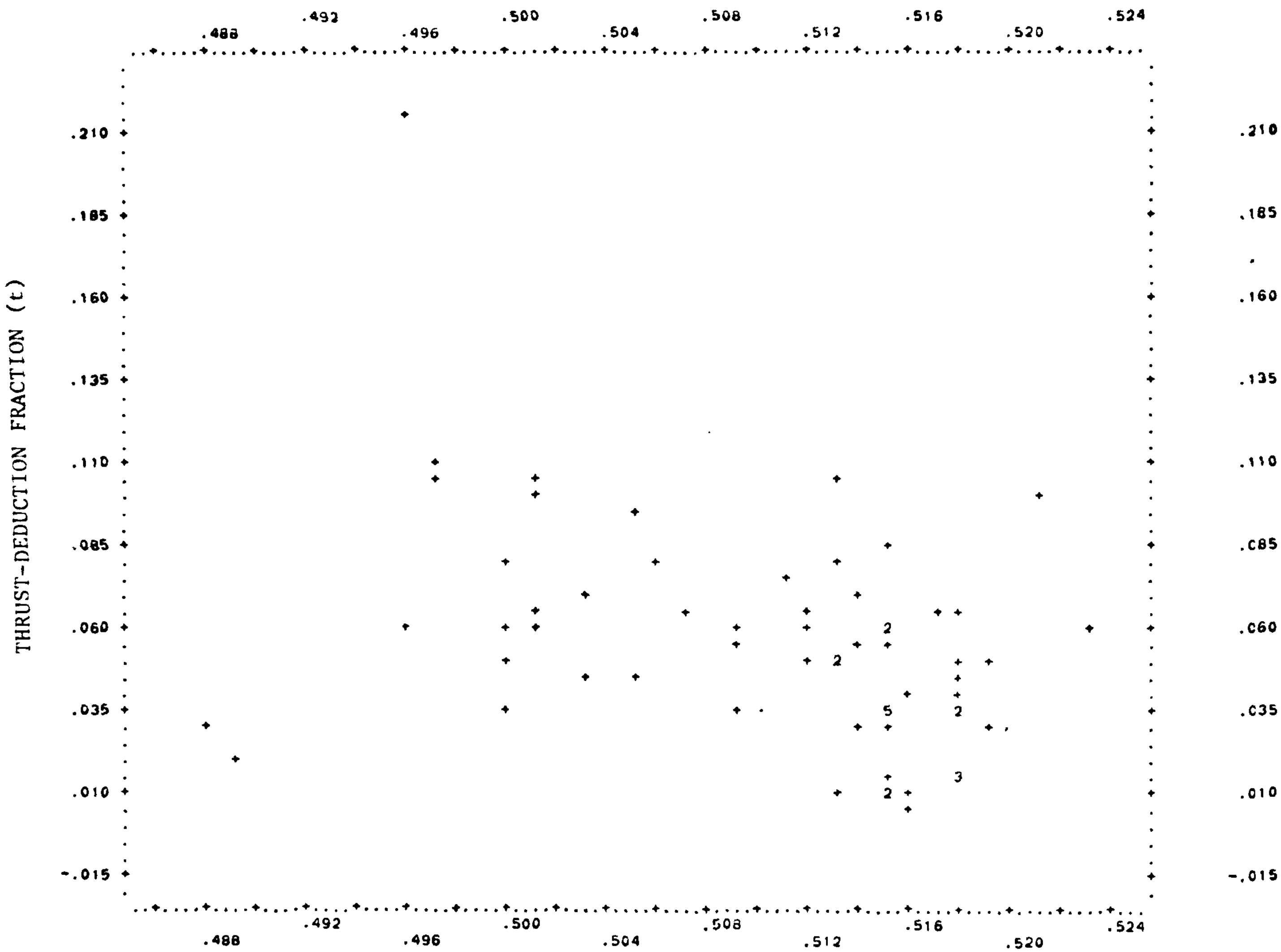


Figure D-11 - Variation of Longitudinal Center of Buoyancy-Waterline Length Ratio and Thrust-Deduction Fraction

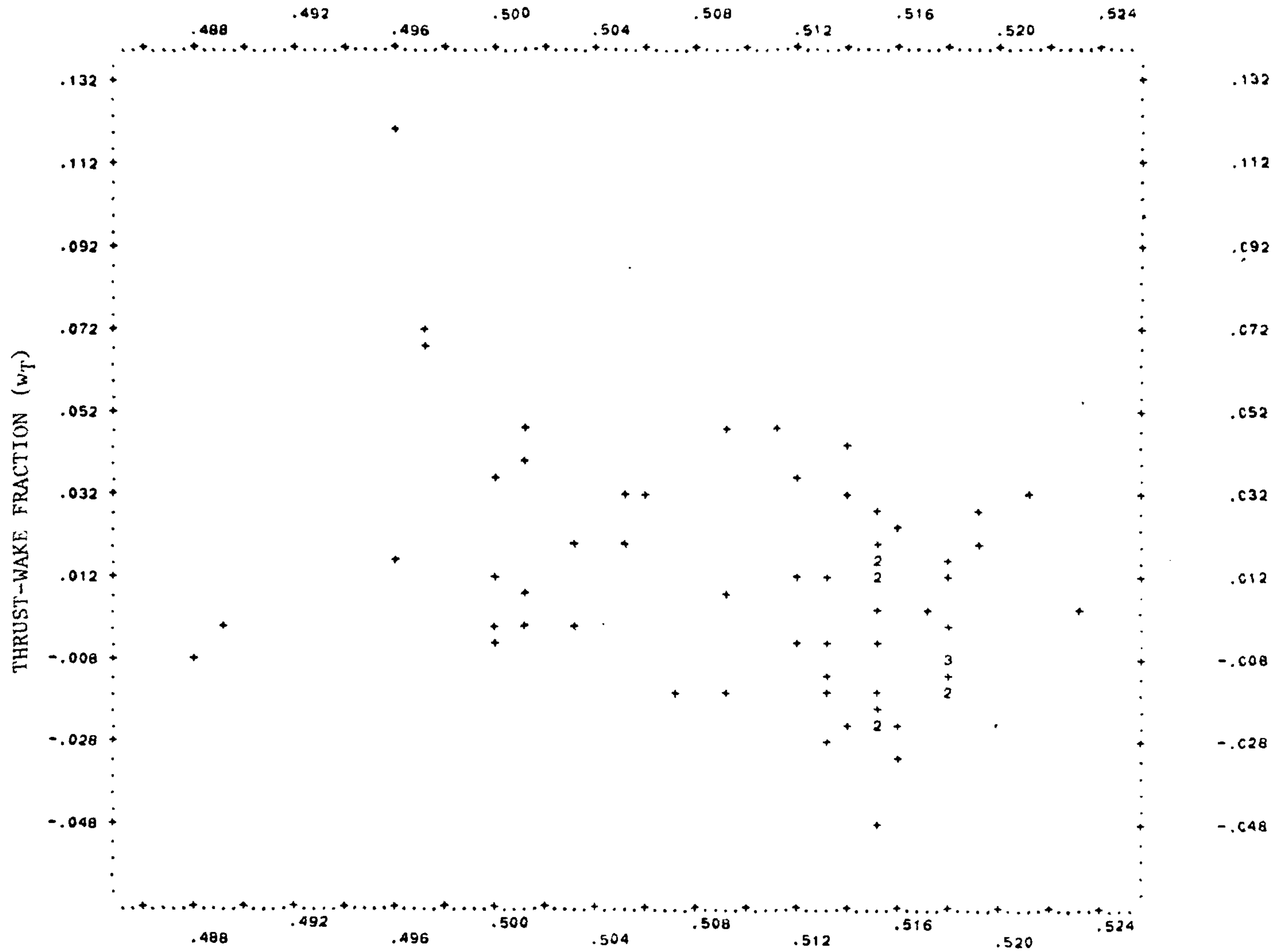


Figure D-12 - Variation of Longitudinal Center of Buoyancy-Waterline Length Ratio and Thrust-Wake Fraction

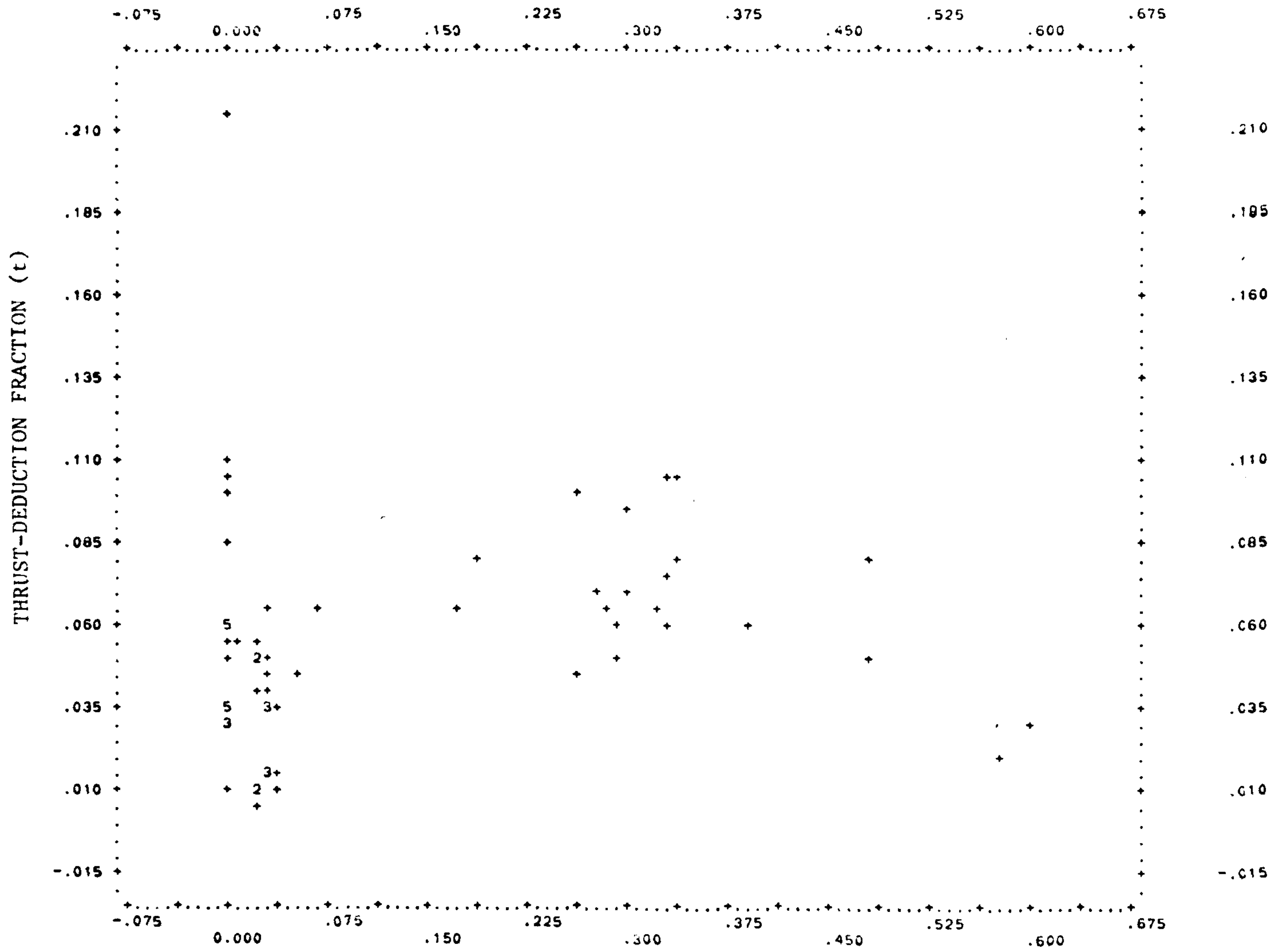


Figure D-13 - Variation of Taylor's 'f' and Thrust-Deduction Fraction

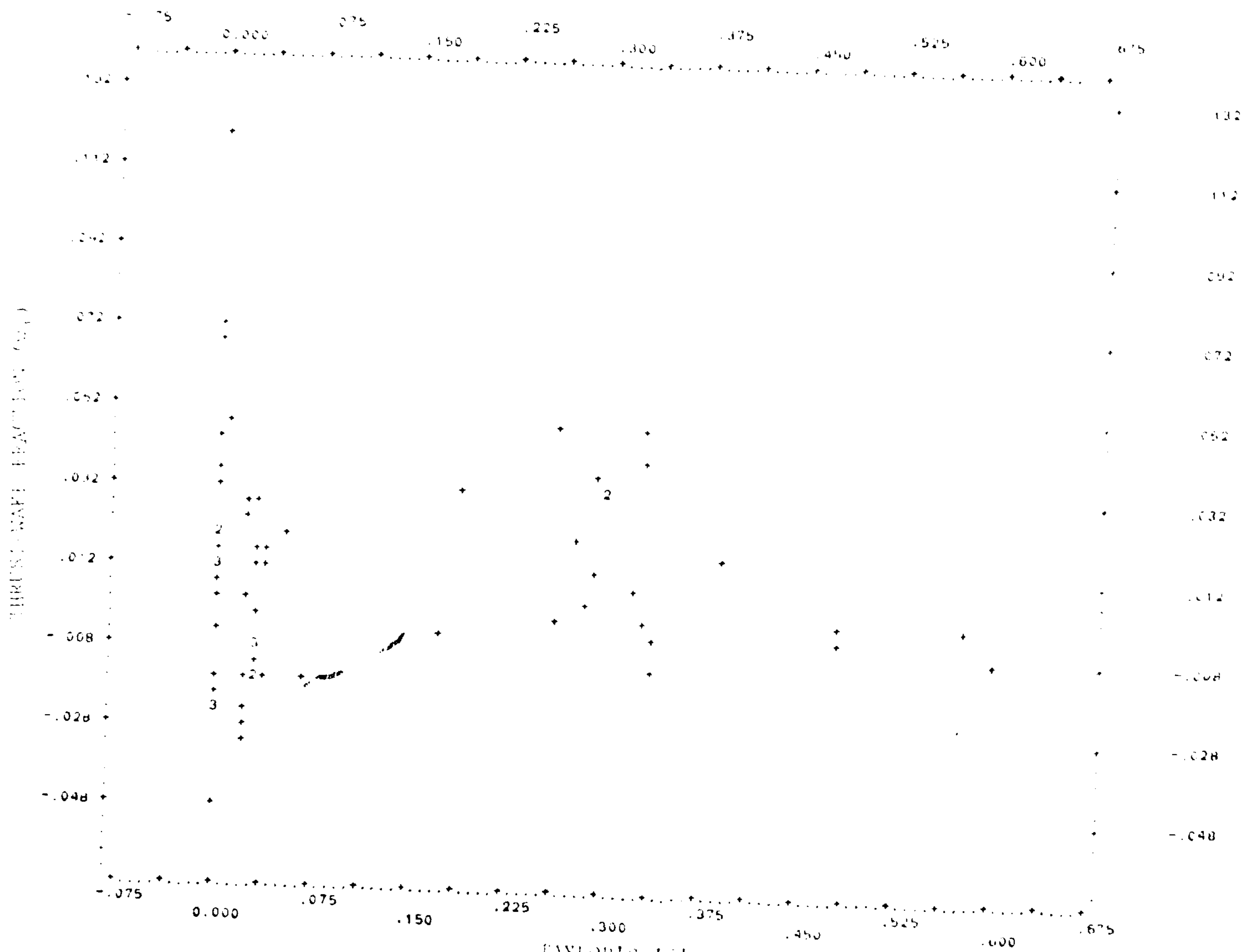


Figure D-16 - Variation of Taylor's 't' and Thrust Wake Fraction

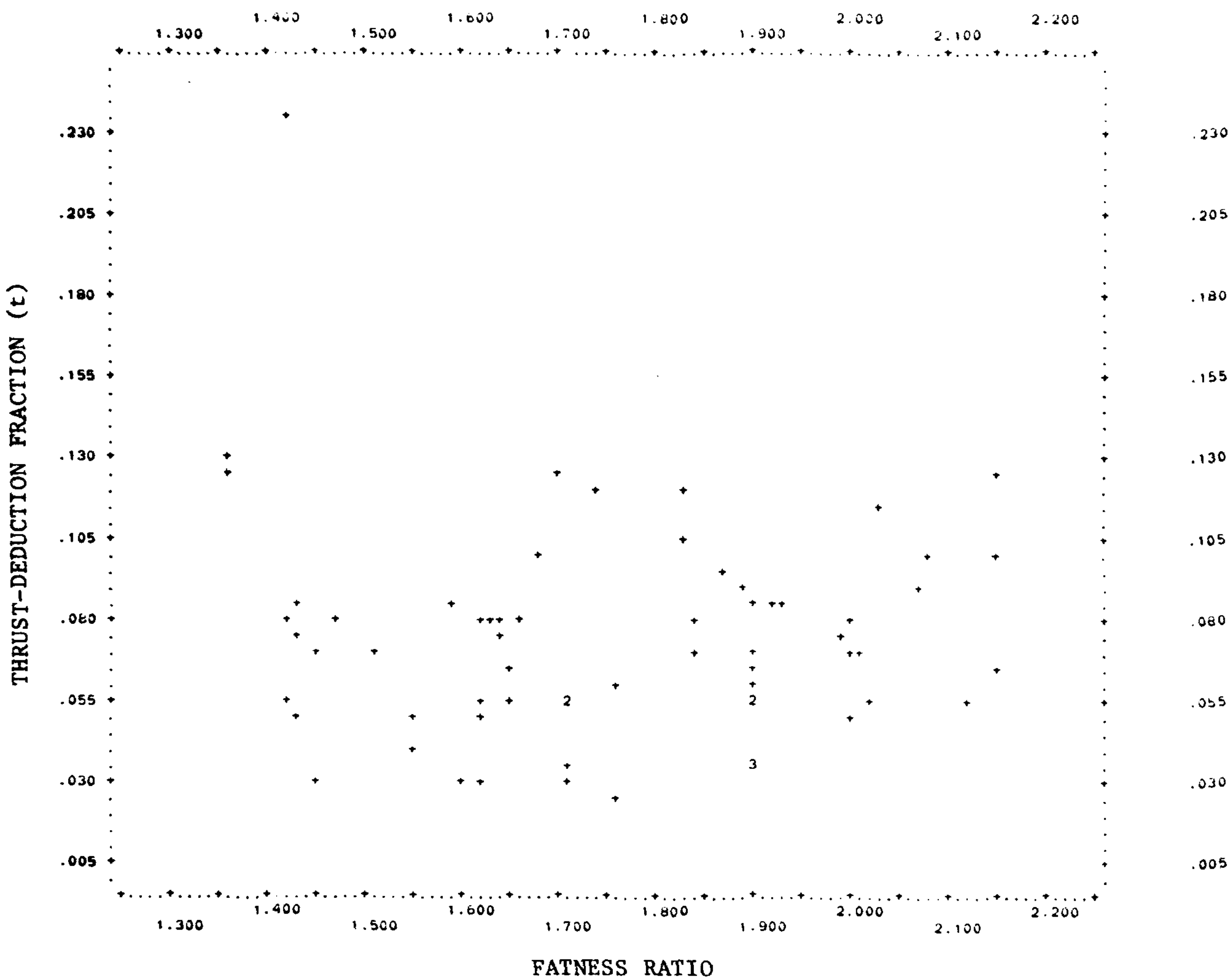


Figure D-15 - Variation of Fatness Ratio and Thrust-Deduction Fraction

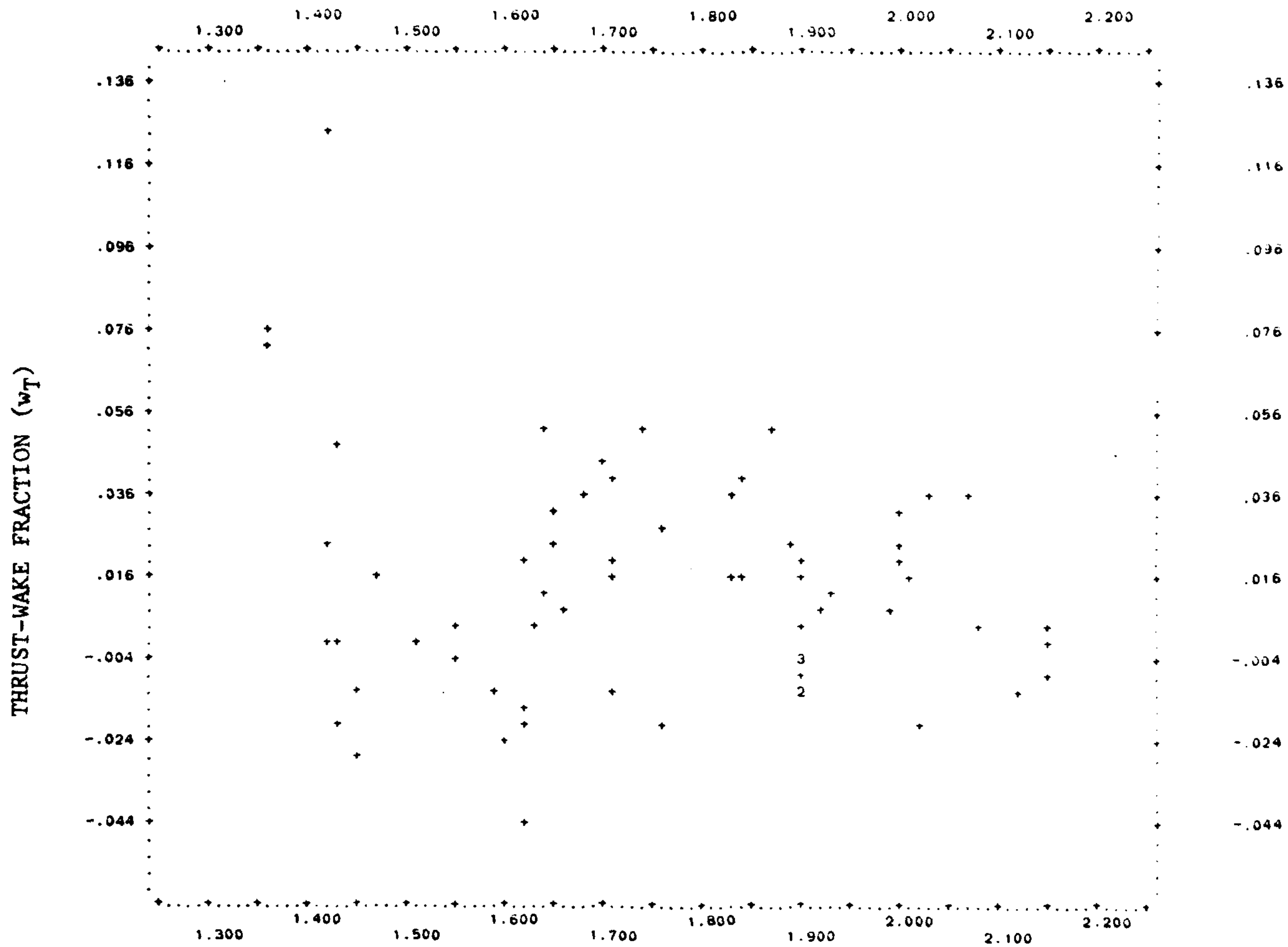


Figure D-16 - Variation of Fatness Ratio and Thrust-Wake Fraction

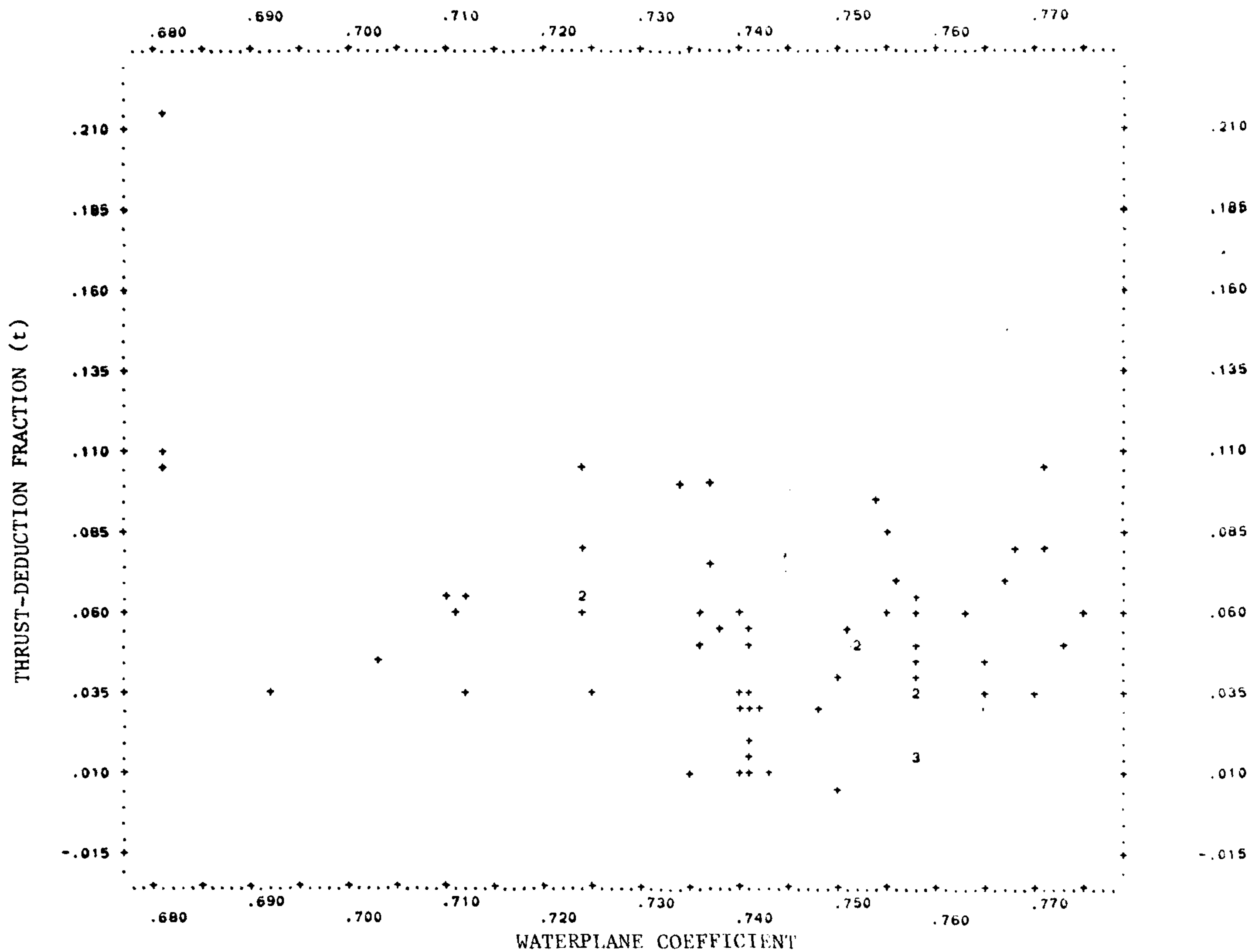


Figure D-17 - Variation of Waterplane Coefficient and Thrust-Deduction Fraction

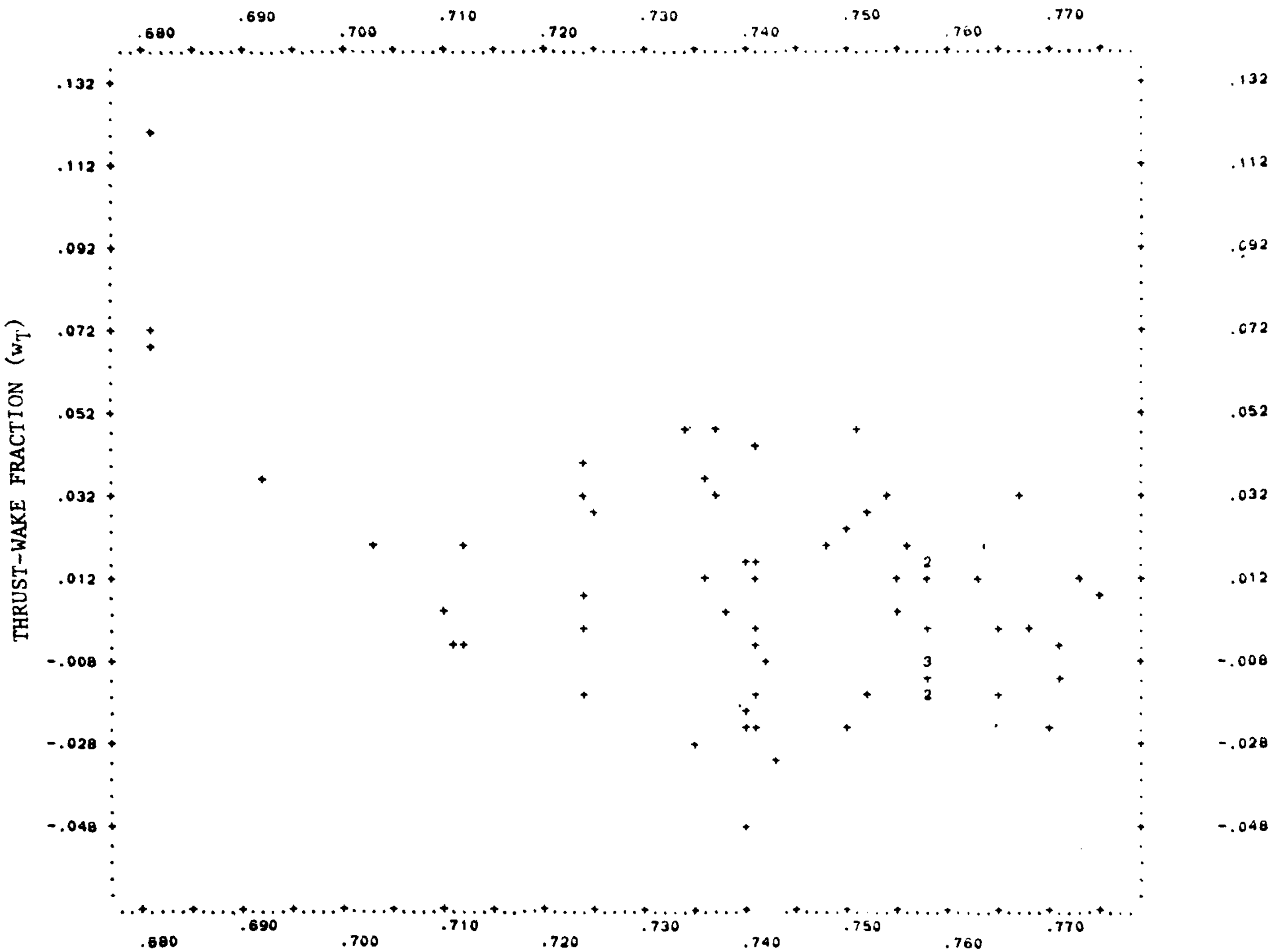


Figure D-18 - Variation of Waterplane Coefficient and Thrust-Wake Fraction

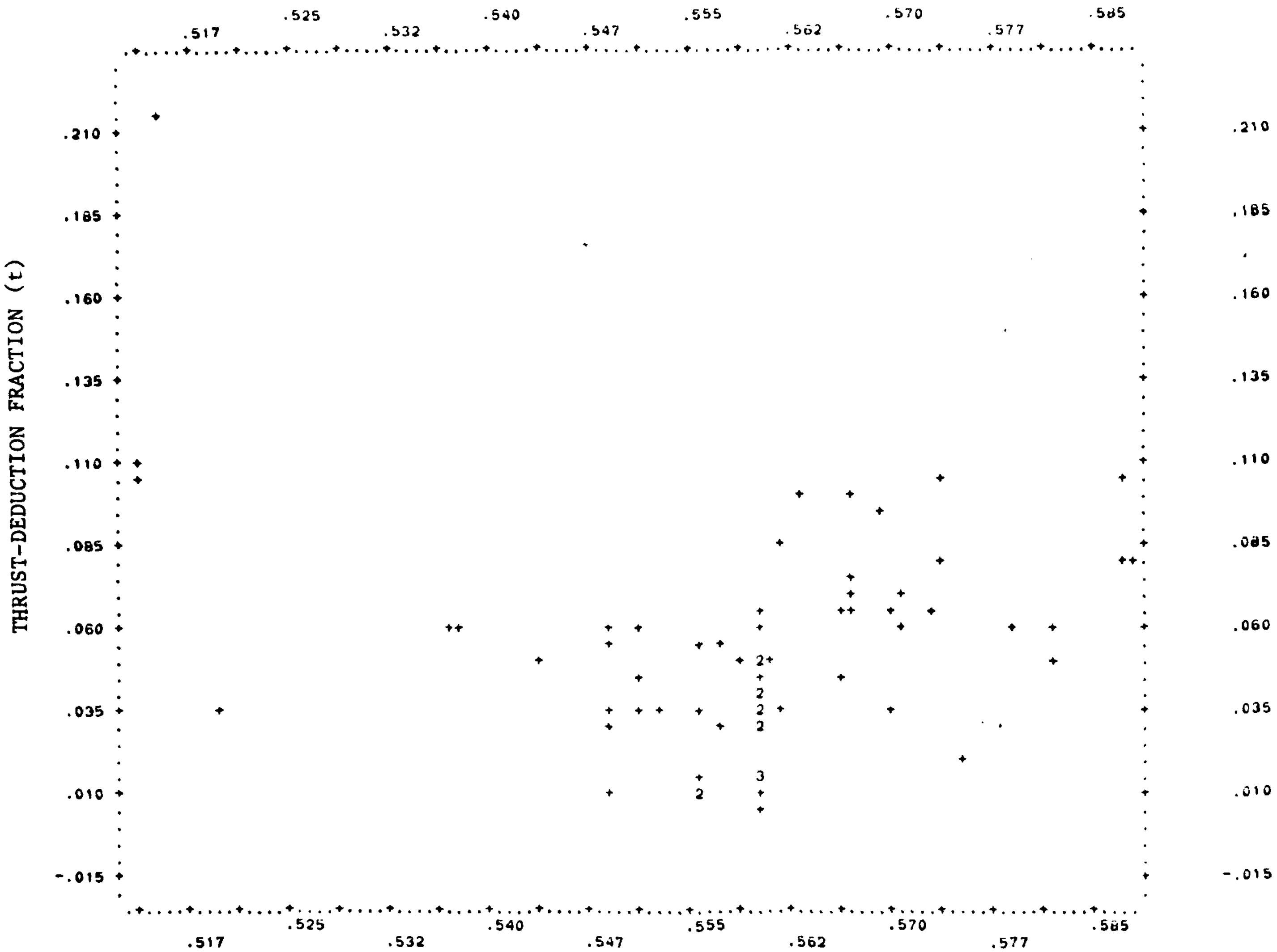


Figure D-19 - Variation of Longitudinal Center of Flotation-Waterline Length Ratio and Thrust-Deduction Fraction

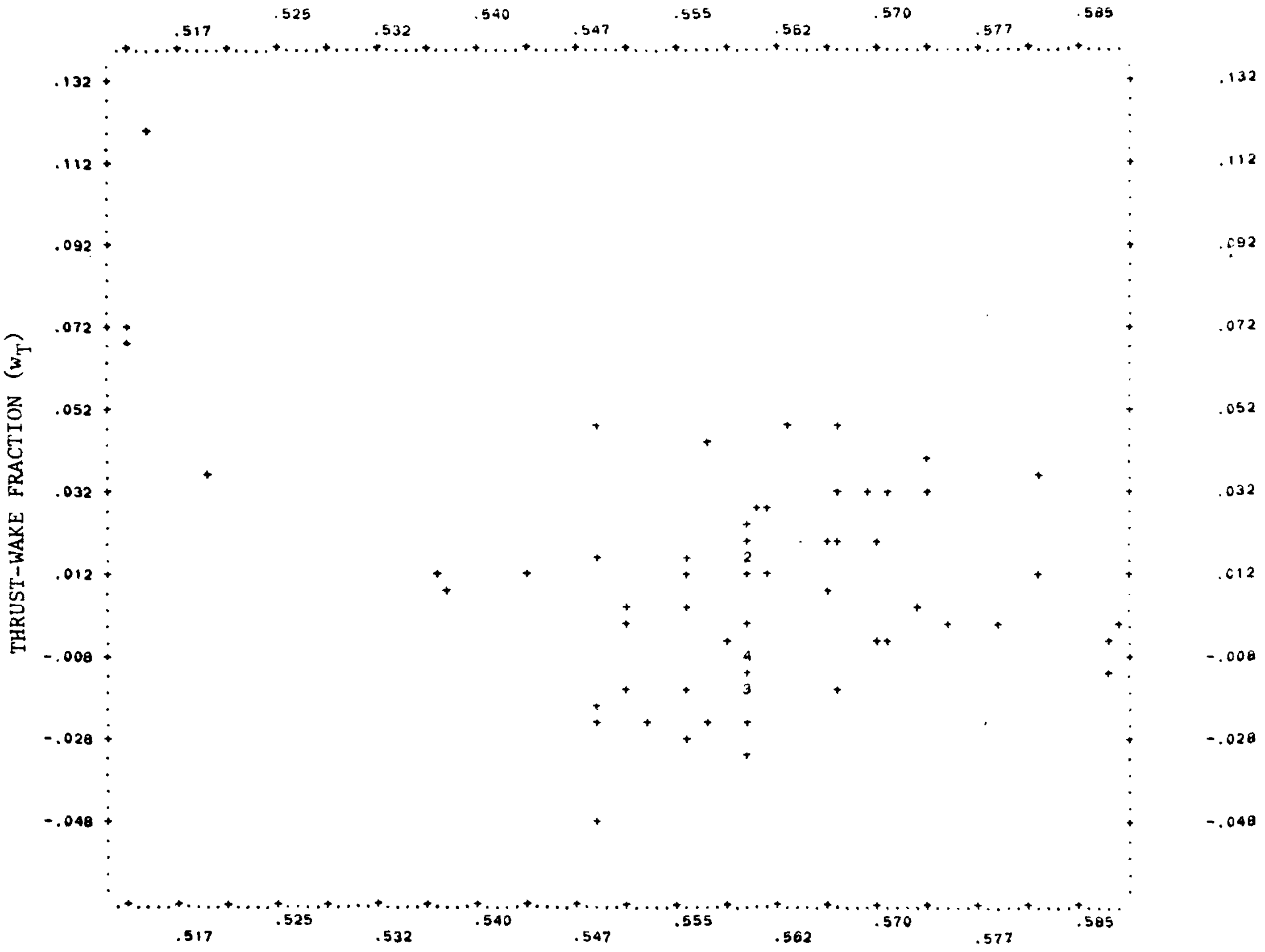


Figure D-20 - Variation of Longitudinal Center of Flotation-Waterline Length Ratio and Thrust-Wake Fraction

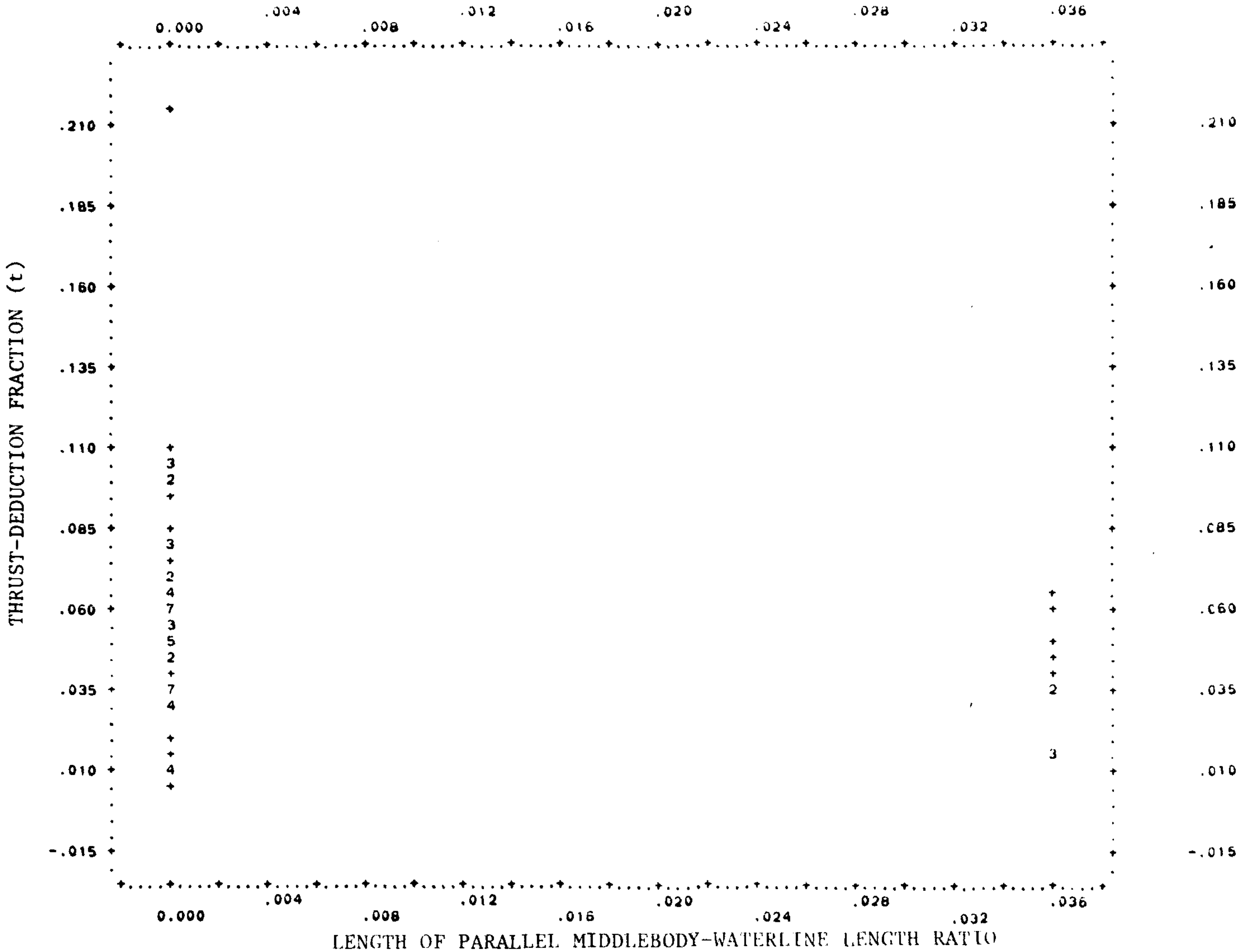


Figure D-21 - Variation of Length of Parallel Middlebody-Waterline Length Ratio and Thrust-Deduction Fraction

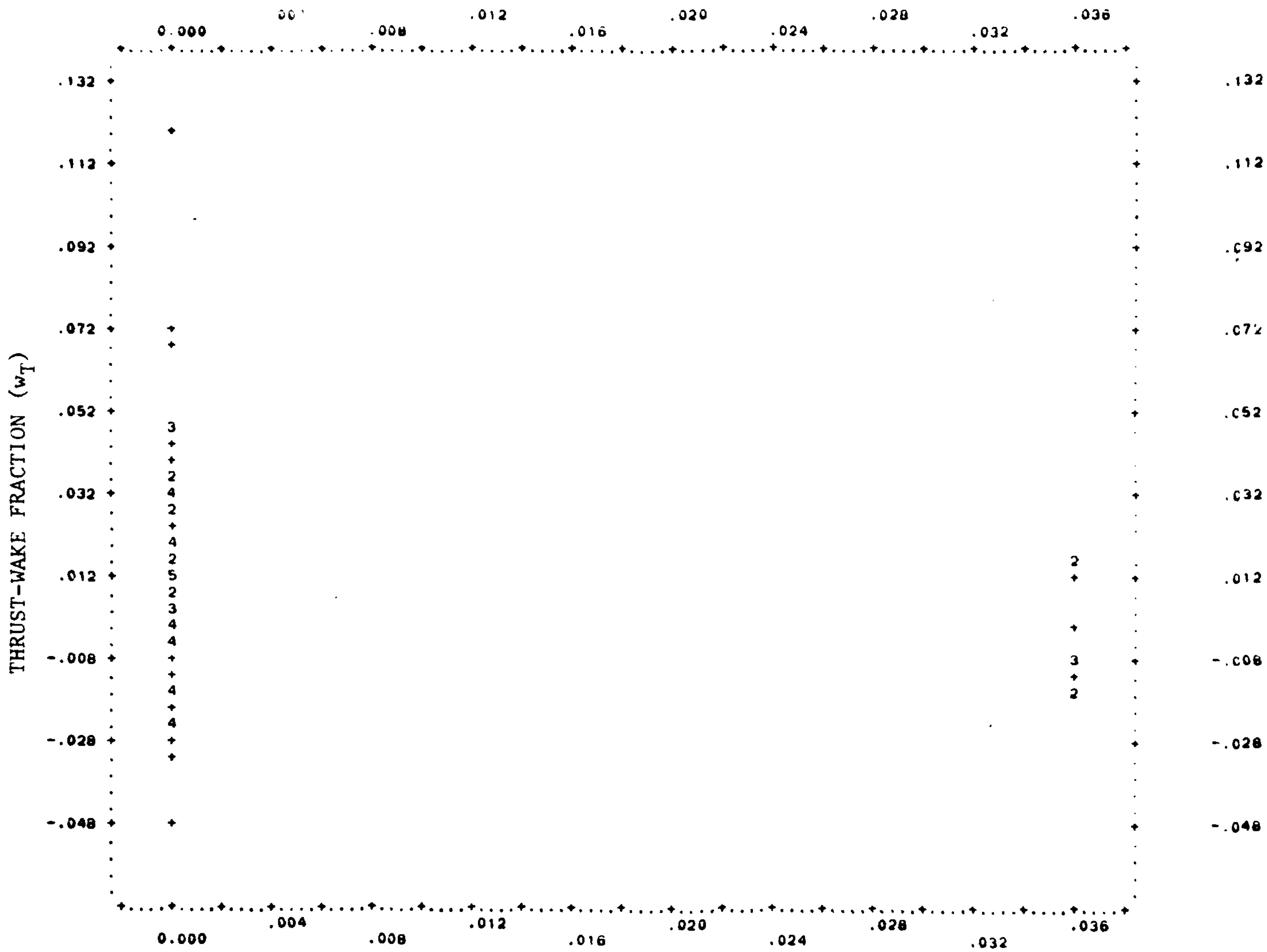


Figure D-22 - Variation of Length of Parallel Middlebody-Waterline Length Ratio and Thrust-Wake Fraction

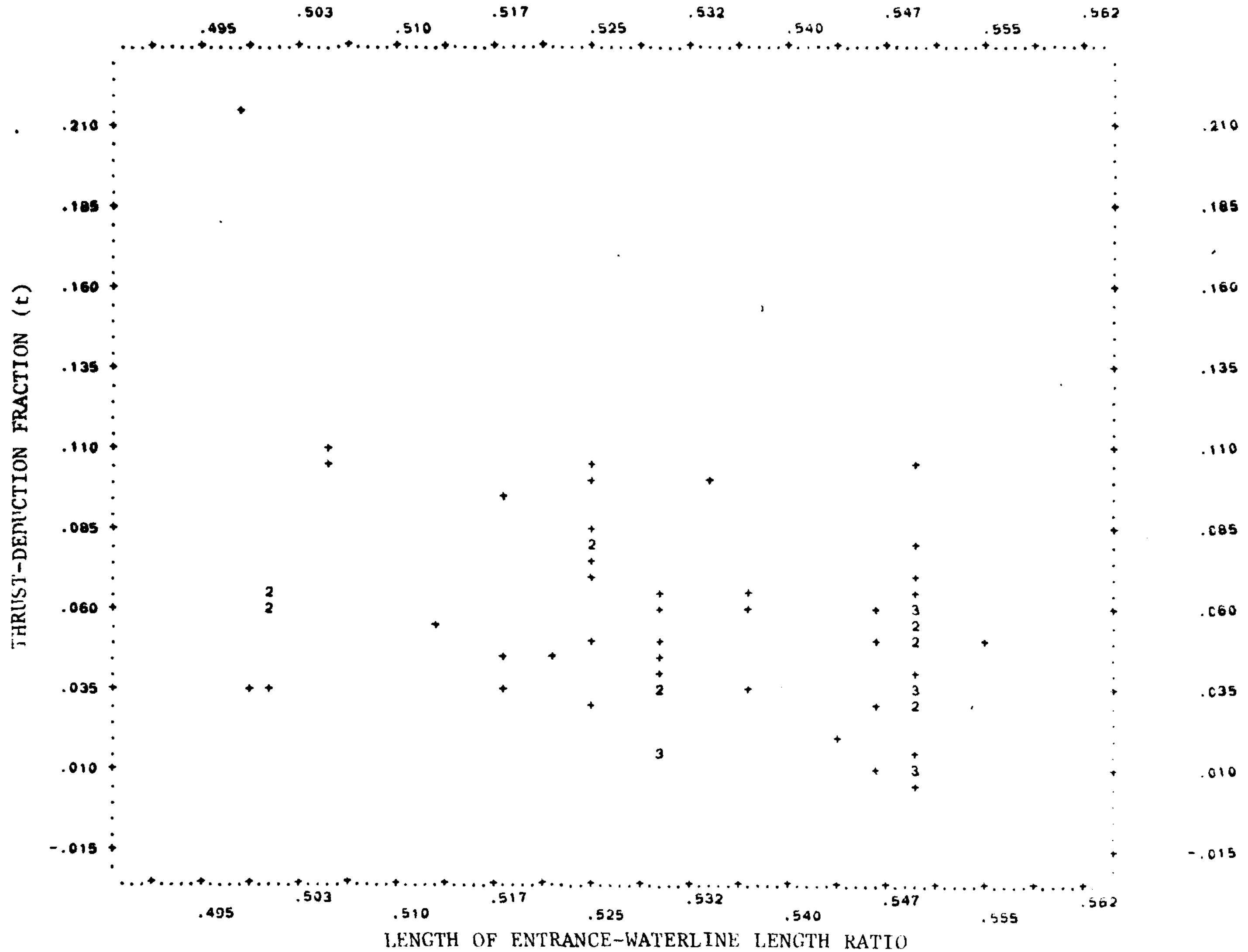


Figure D-23 - Variation of Length of Entrance-Waterline Length Ratio and Thrust-Deduction Fraction

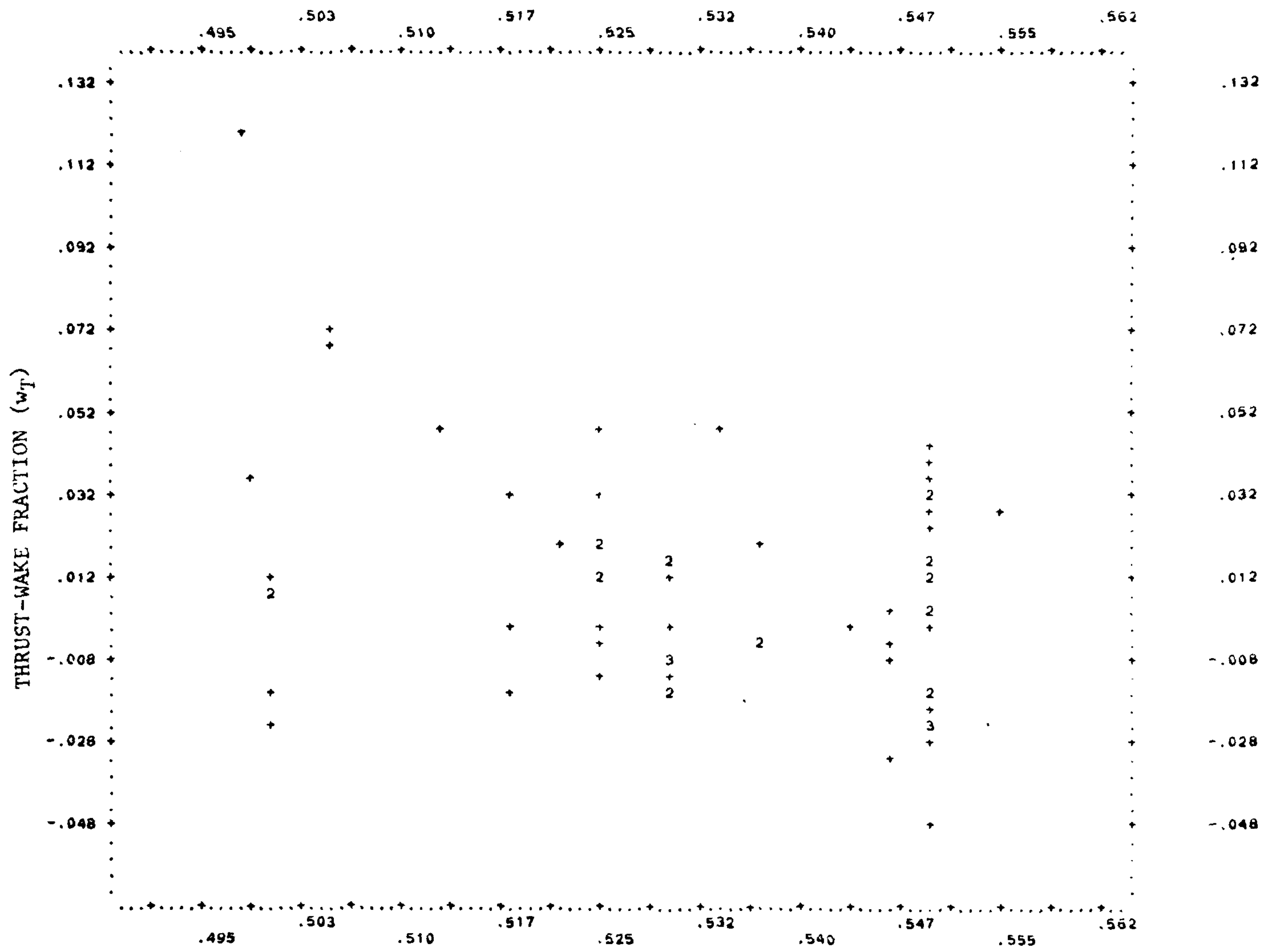


Figure D-24 - Variation of Length of Entrance-Waterline Length Ratio and Thrust-Wake Fraction

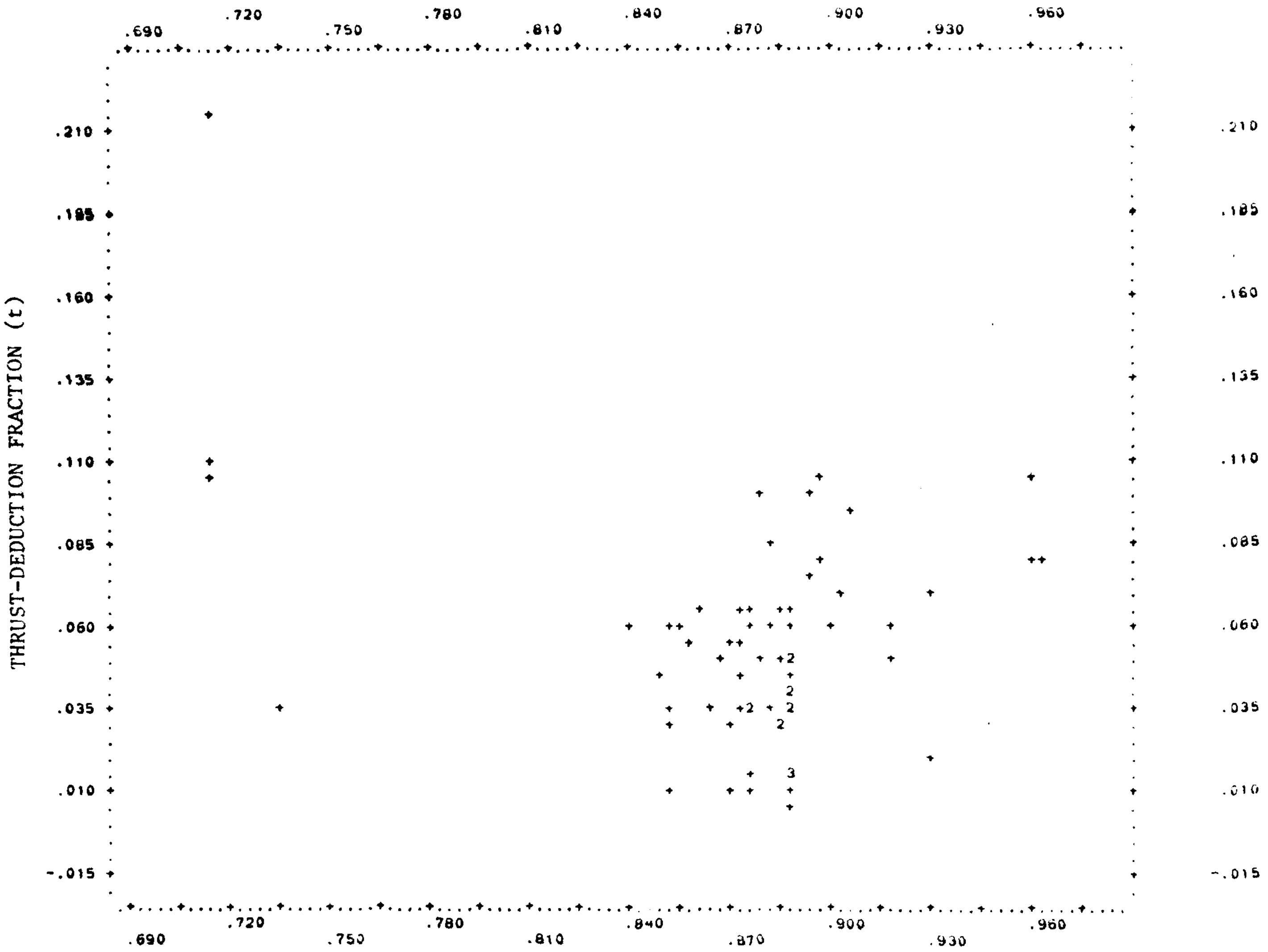


Figure D-25 - Variation of Afterbody Waterplane Coefficient and Thrust-Deduction Fraction

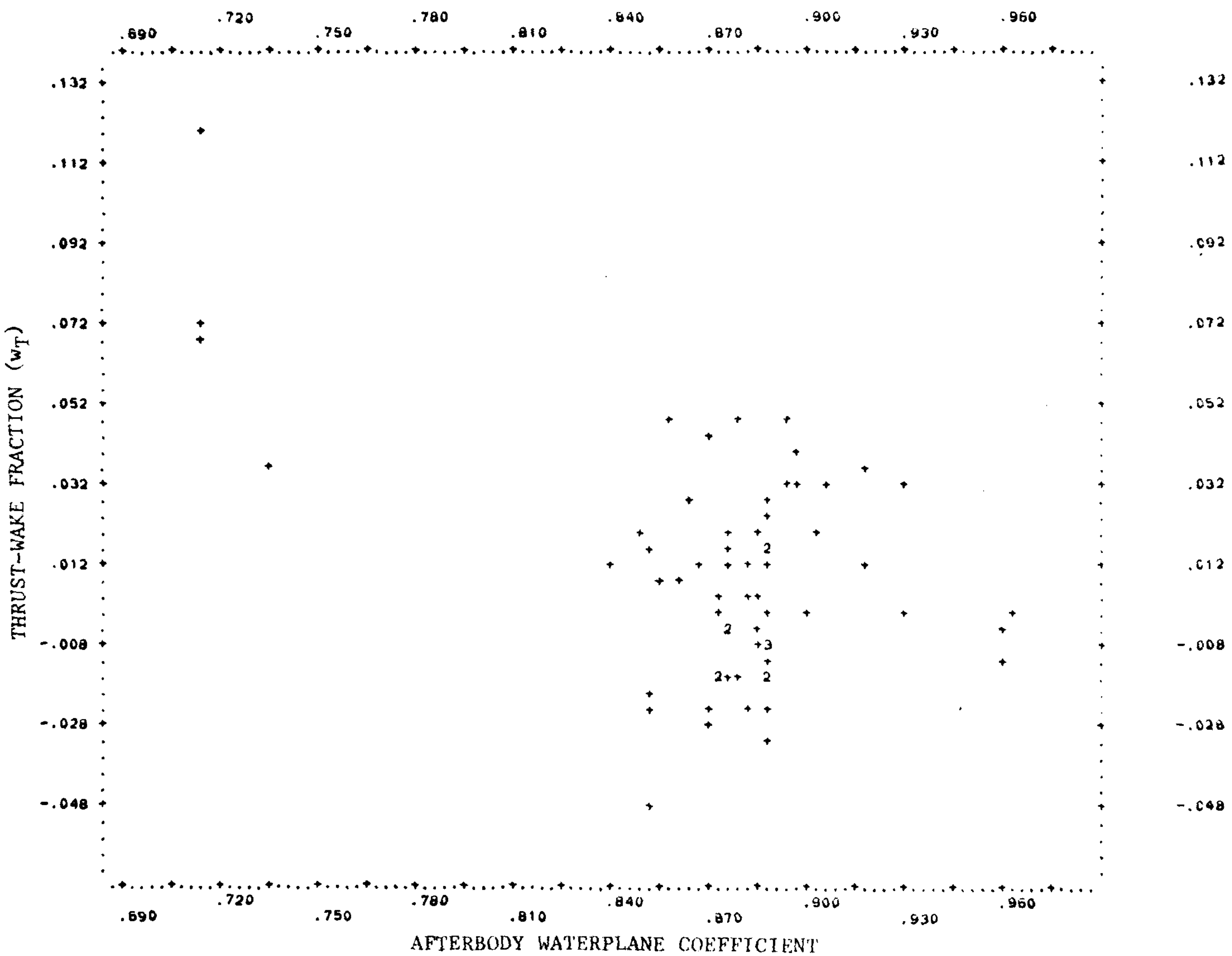


Figure D-26 - Variation of Afterbody Waterplane Coefficient and Thrust-Wake Fraction

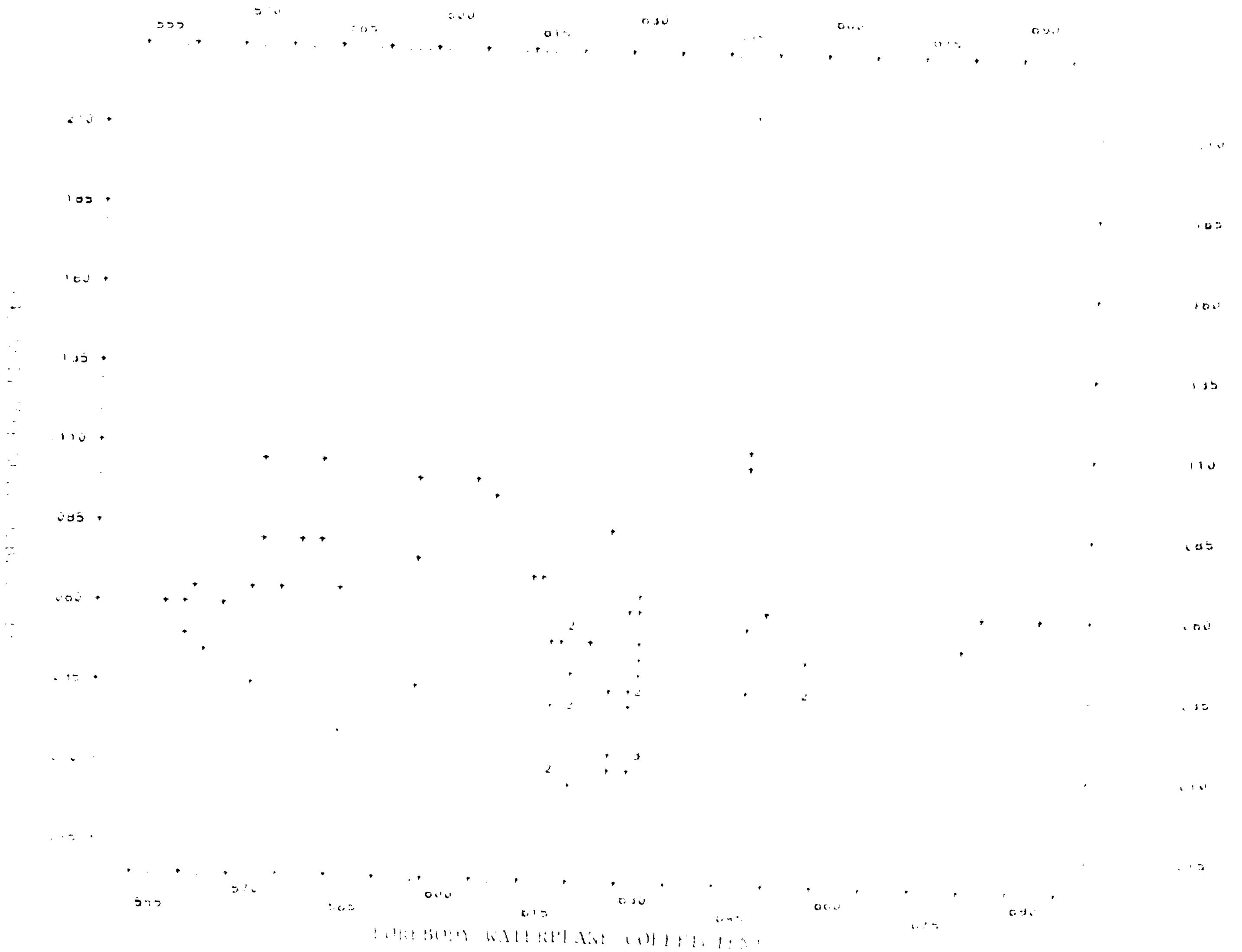


Figure [illegible] Variation of Forebody Waterplane Coefficient and Thrust Deduction Fraction

AD-A092 449 DAVID W TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CE--ETC F/G 13/10
PREDICTION OF THRUST-DEDUCTION AND WAKE FRACTIONS FOR TWIN-SCRE--ETC(U)
NOV 80 R B HURWITZ
UNCLASSIFIED DTNSRDC/SPD-693-02 NL

2 OF 2
AD
A092449

END
DATE
FILMED
1-81
DTIC

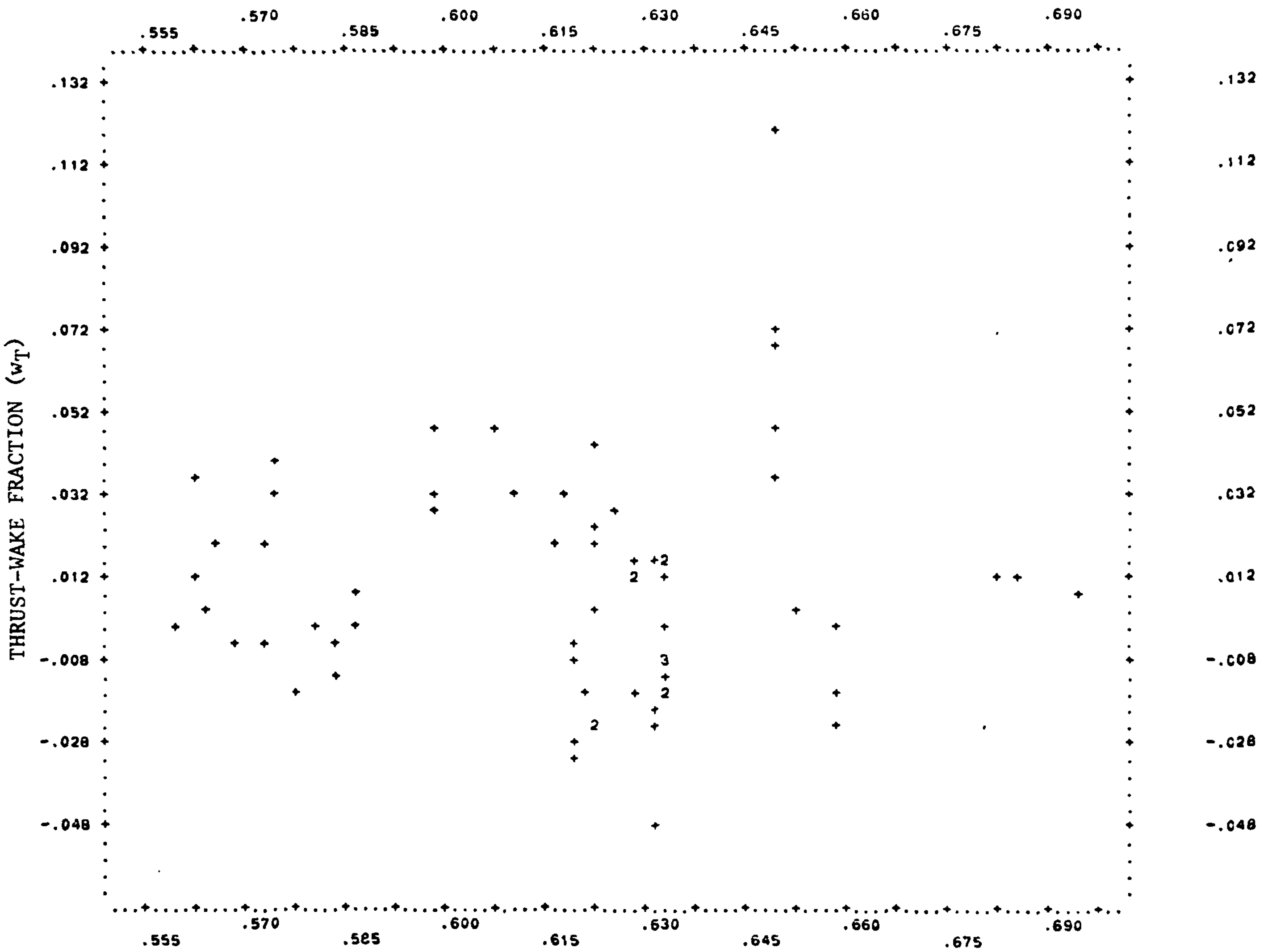


Figure D-28 - Variation of Forebody Waterplane Coefficient and Thrust-Wake Fraction

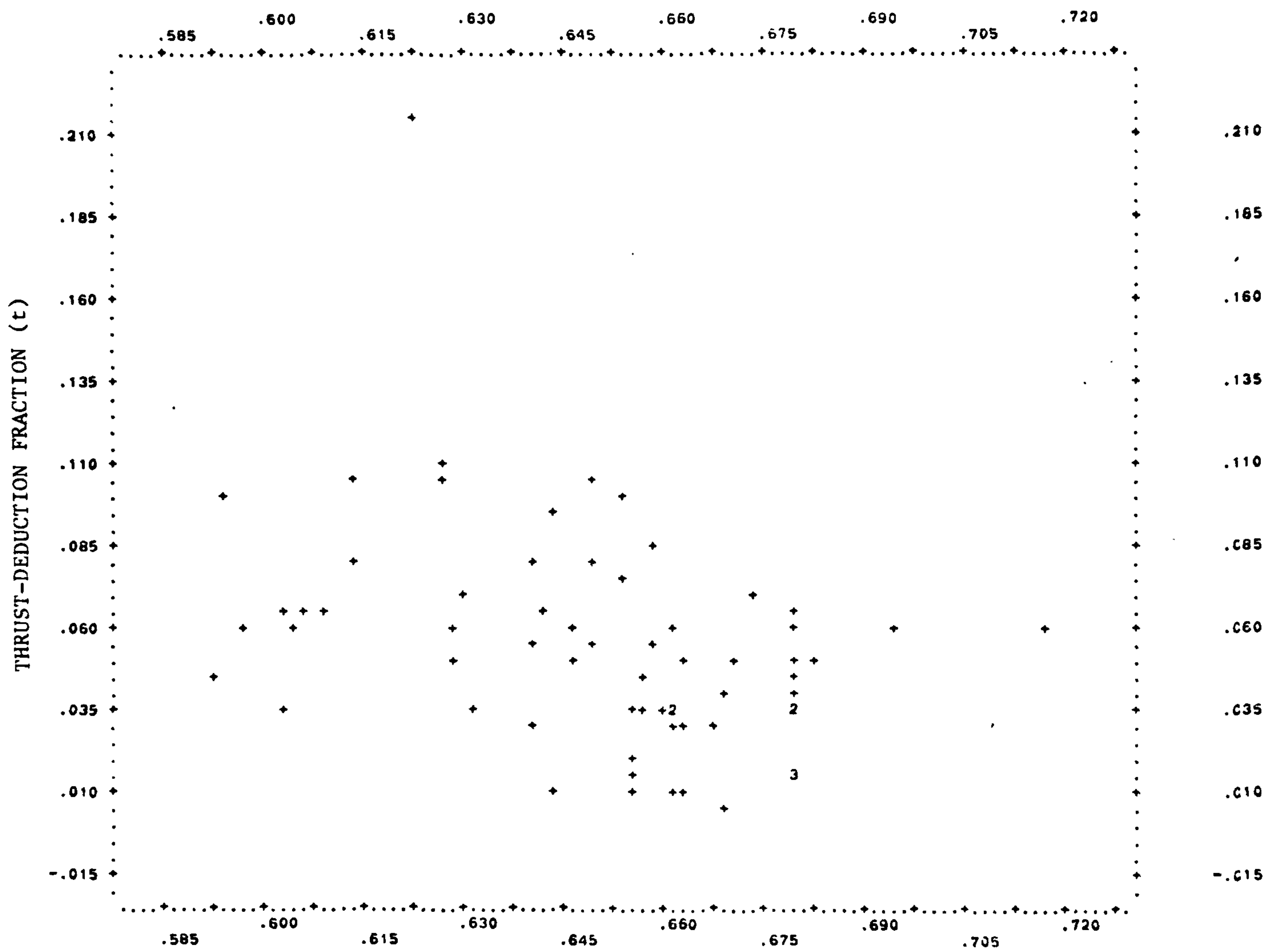


Figure D-29 - Variation of Afterbody Prismatic Coefficient and Thrust-Deduction Fraction

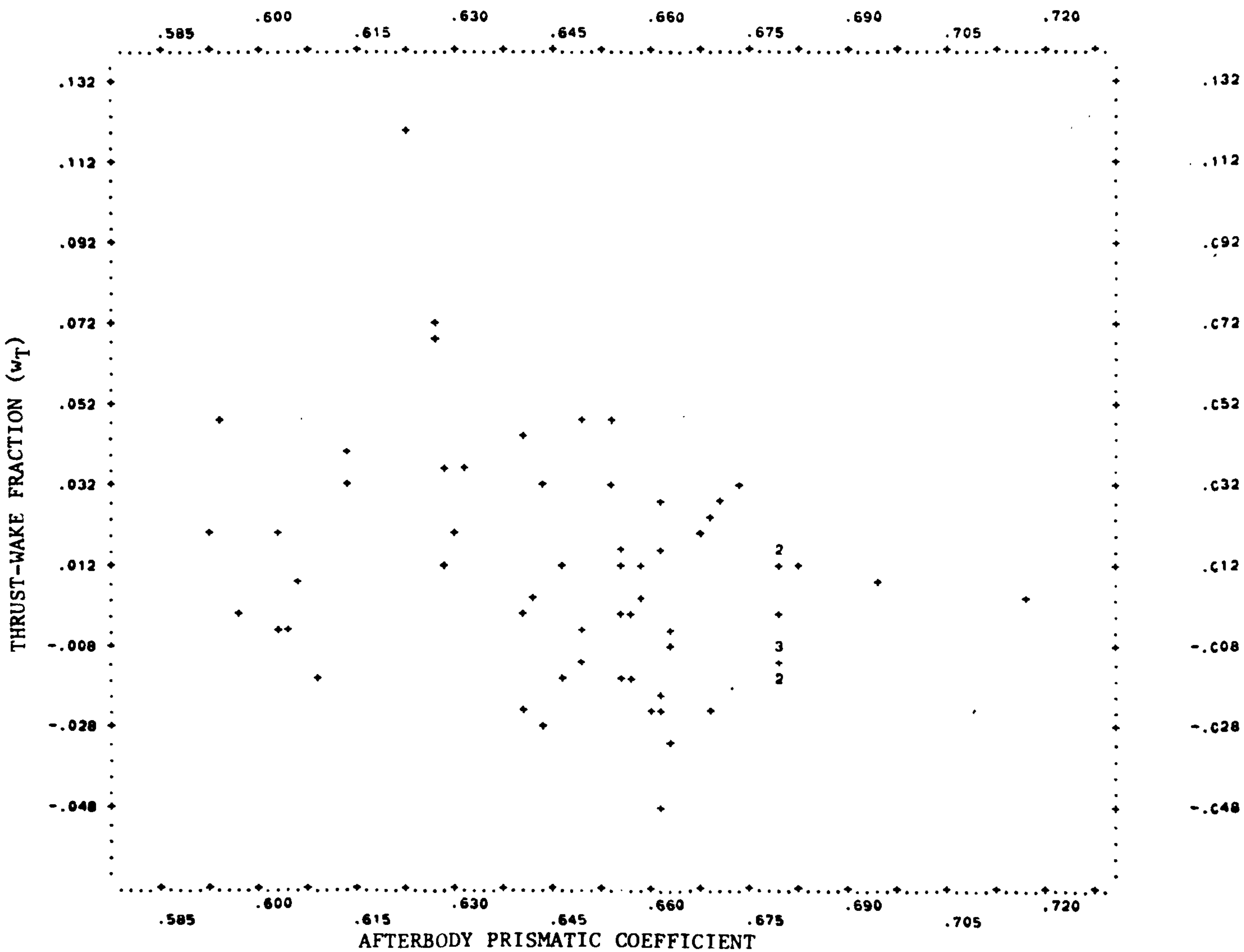
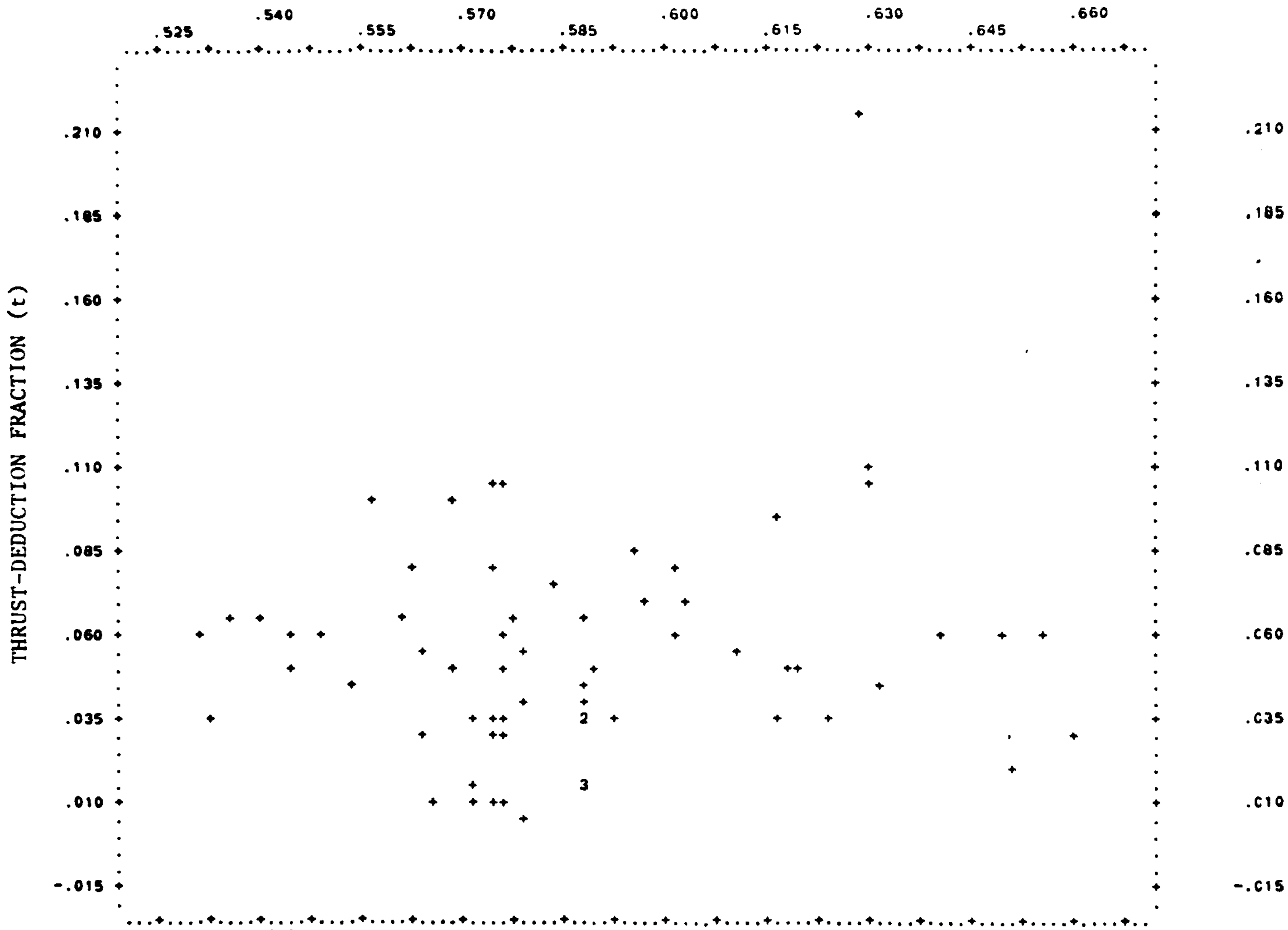


Figure D-30 - Variation of Afterbody Prismatic Coefficient and Thrust-Wake Fraction



FOREBODY PRISMATIC COEFFICIENT
Figure D-31 - Variation of Forebodv Prismatic Coefficient and Thrust-Deduction Fraction

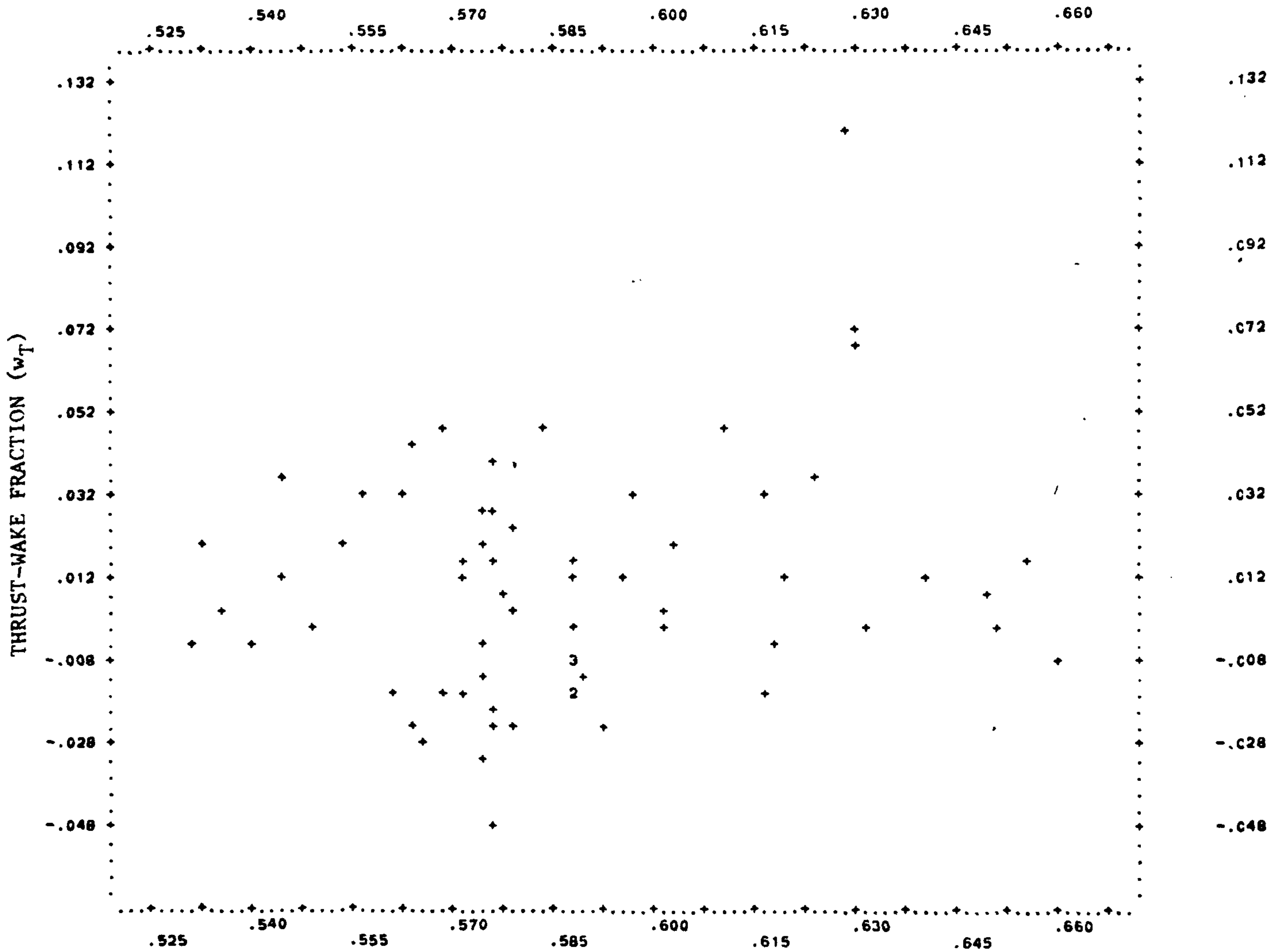


Figure D-32 - Variation of Forebody Prismatic Coefficient and Thrust-Wake Fraction

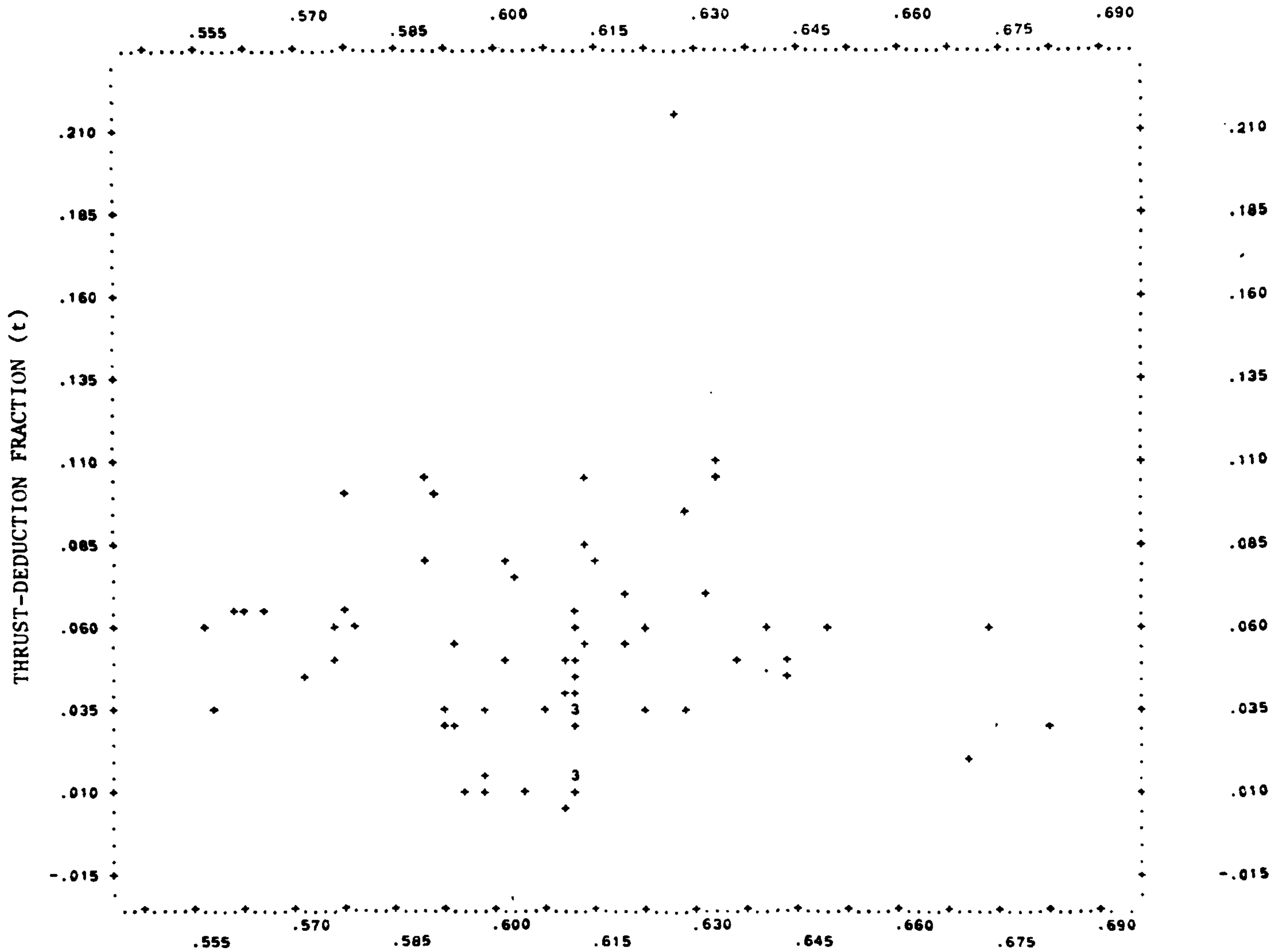


Figure D-33 - Variation of Entrance Prismatic Coefficient and Thrust-Deduction Fraction

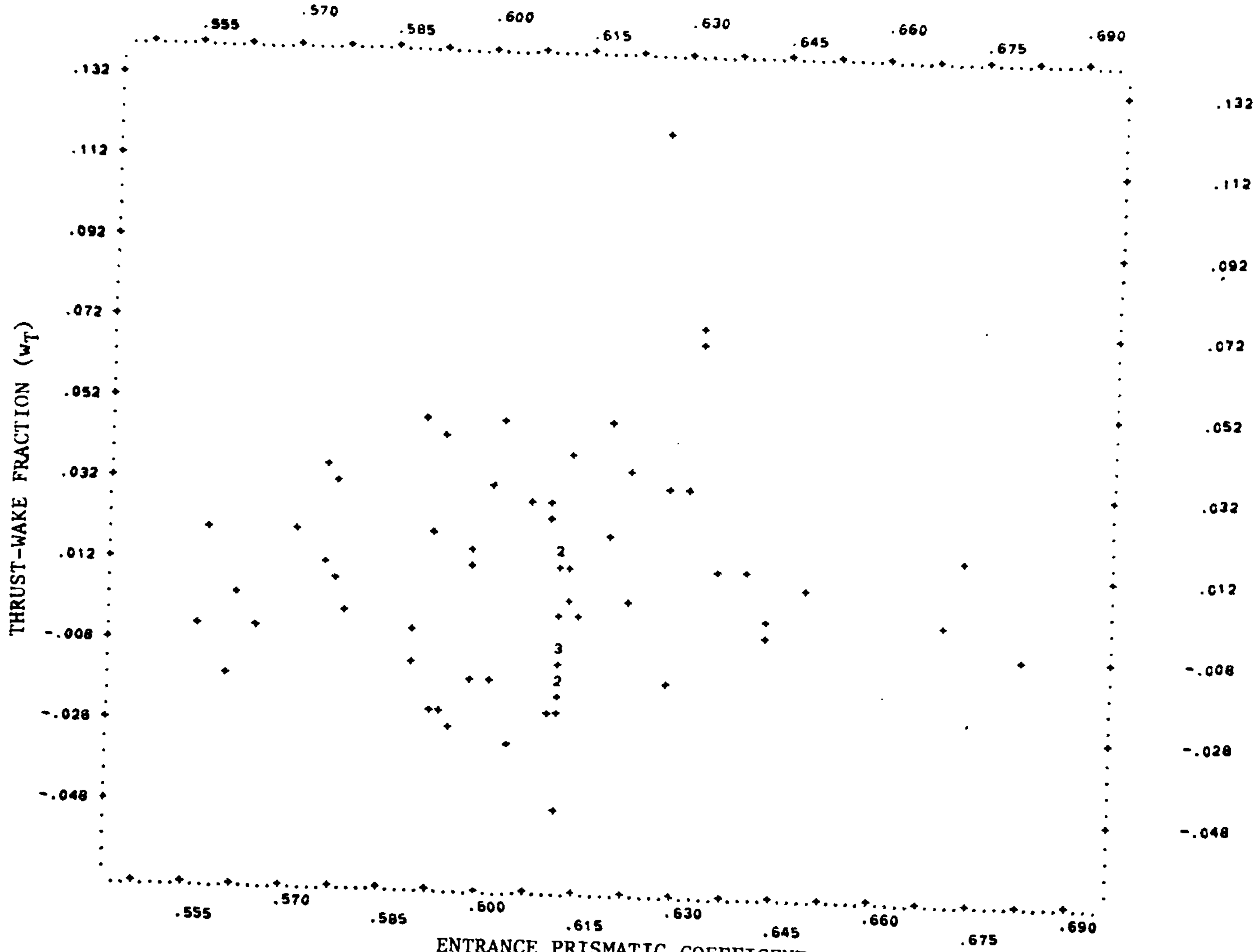


Figure D-34 - Variation of Entrance Prismatic Coefficient and Thrust-Wake Fraction

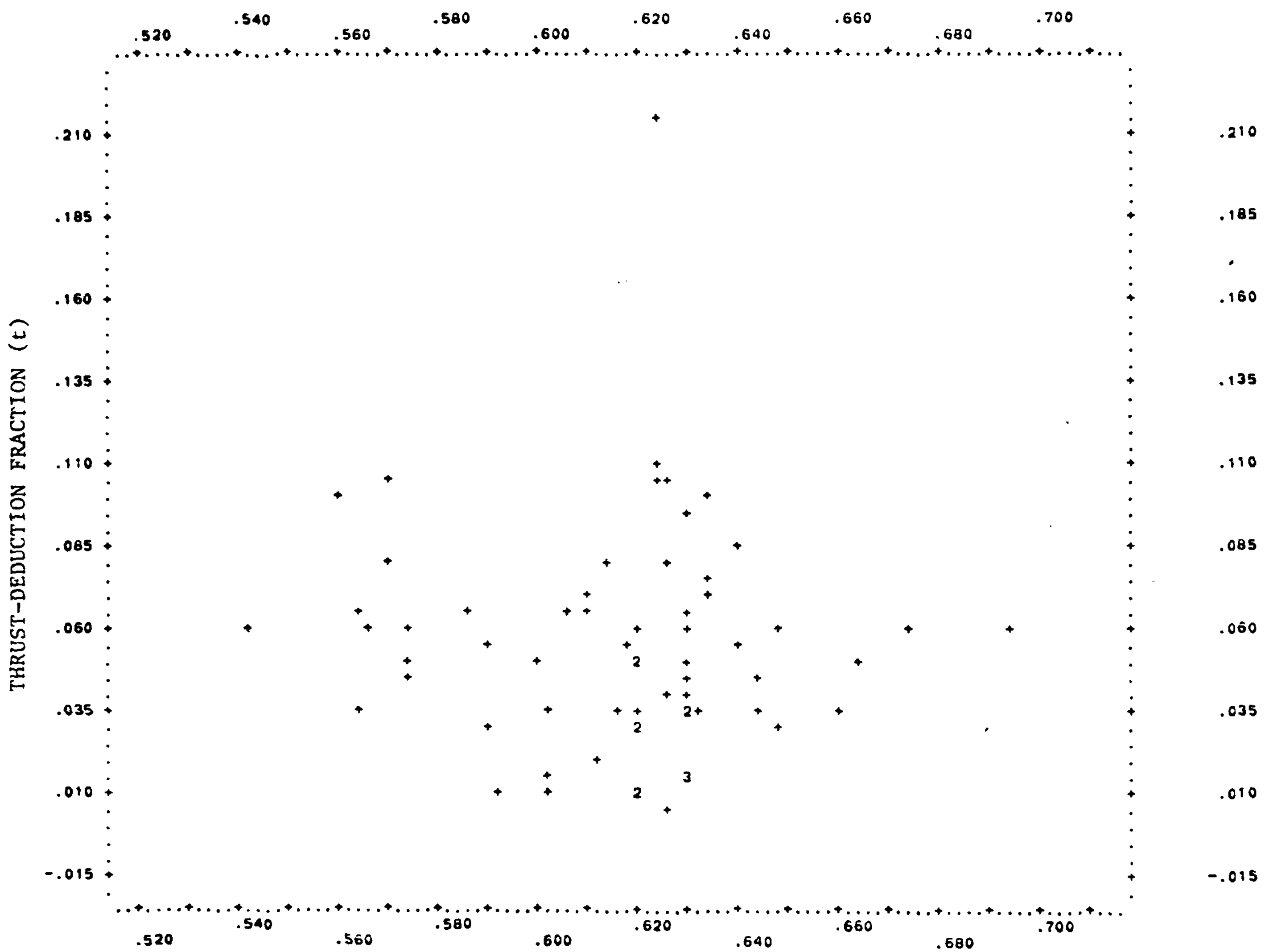


Figure D-35 - Variation of Run Prismatic Coefficient and Thrust-Deduction Fraction

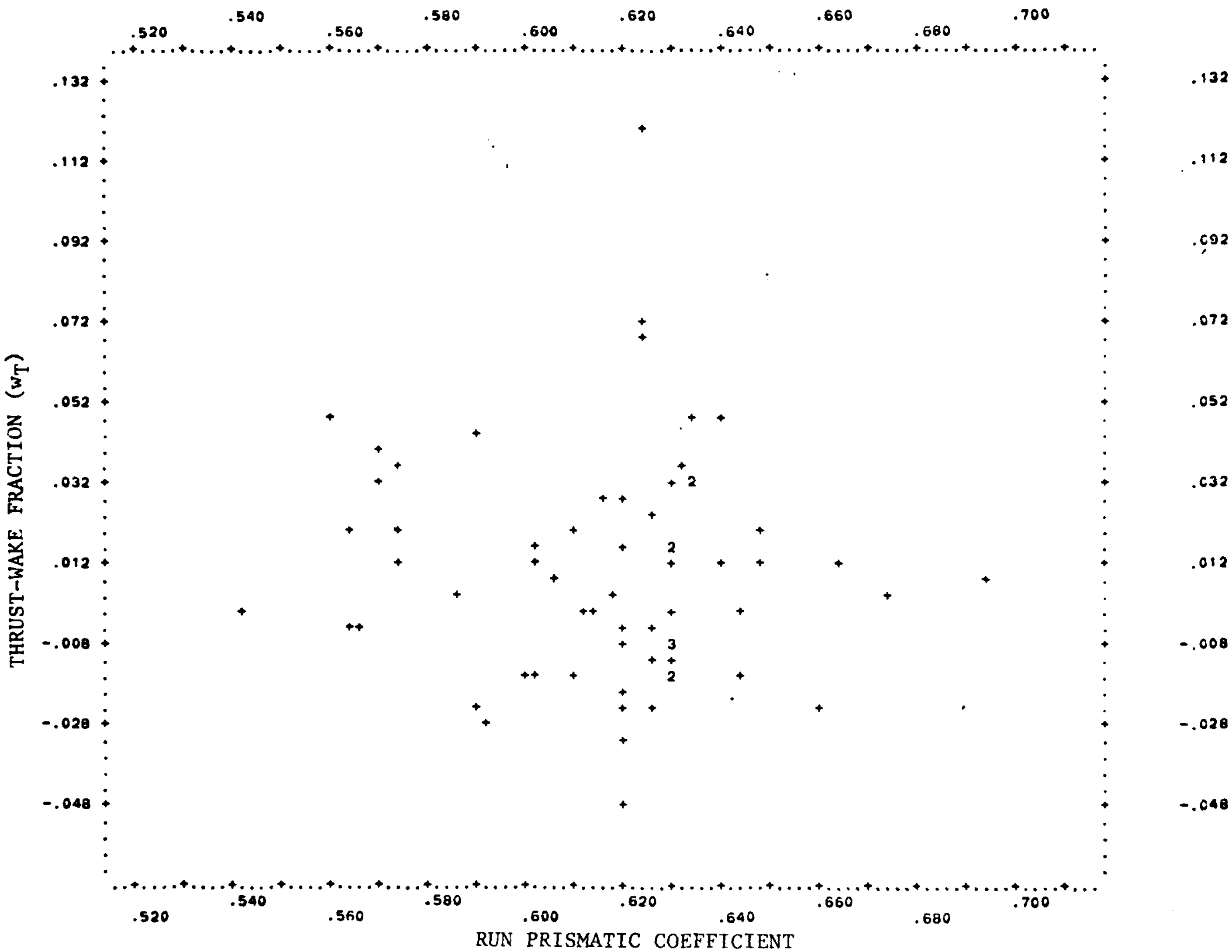


Figure D-36 - Variation of Run Prismatic Coefficient and Thrust-Wake Fraction

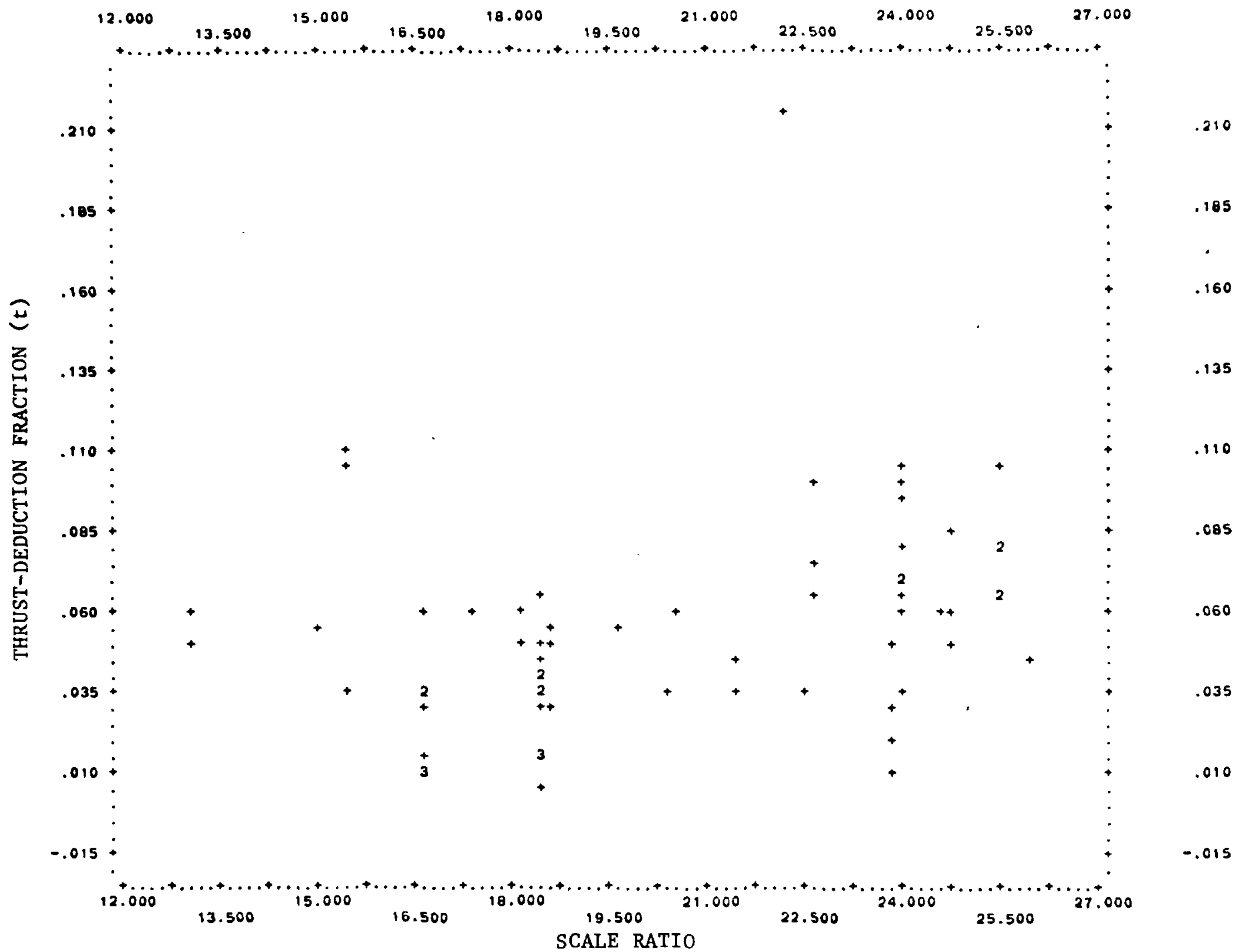


Figure D-37 - Variation of Scale Ratio and Thrust-Deduction Fraction

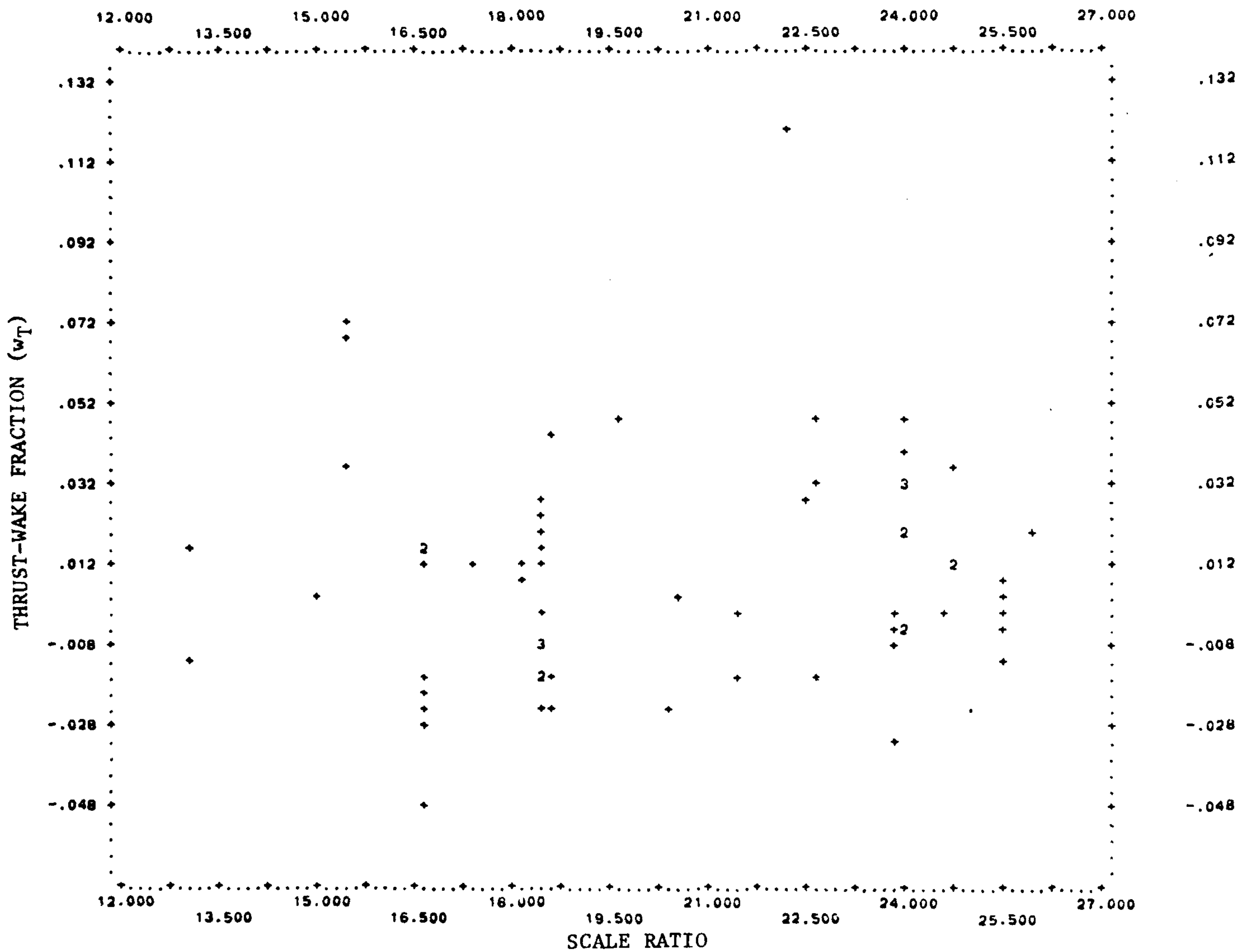


Figure D-38 - Variation of Scale Ratio and Thrust-Wake Fraction

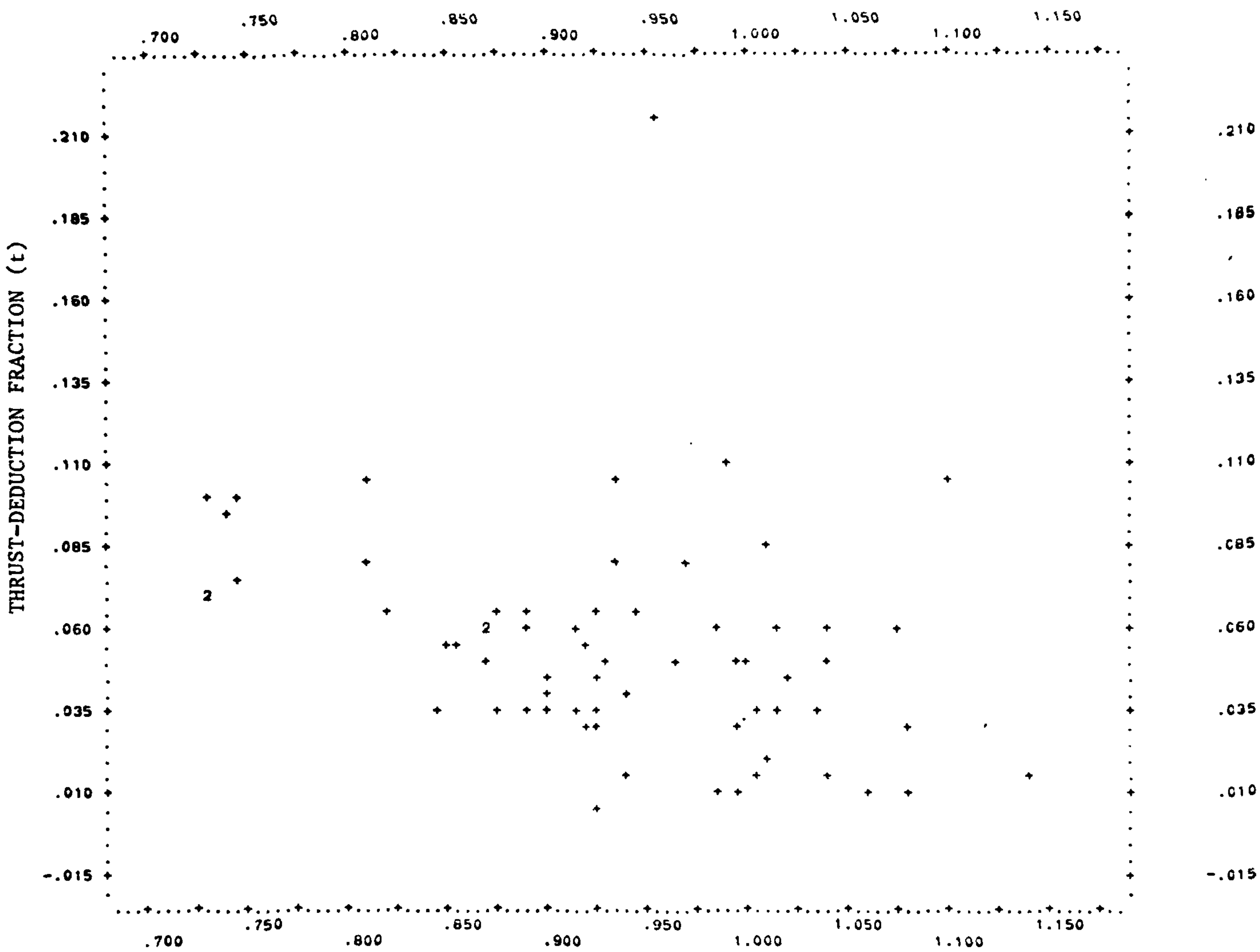


Figure D-39 - Variation of Propeller Diameter-Draft Ratio and Thrust-Deduction Fraction

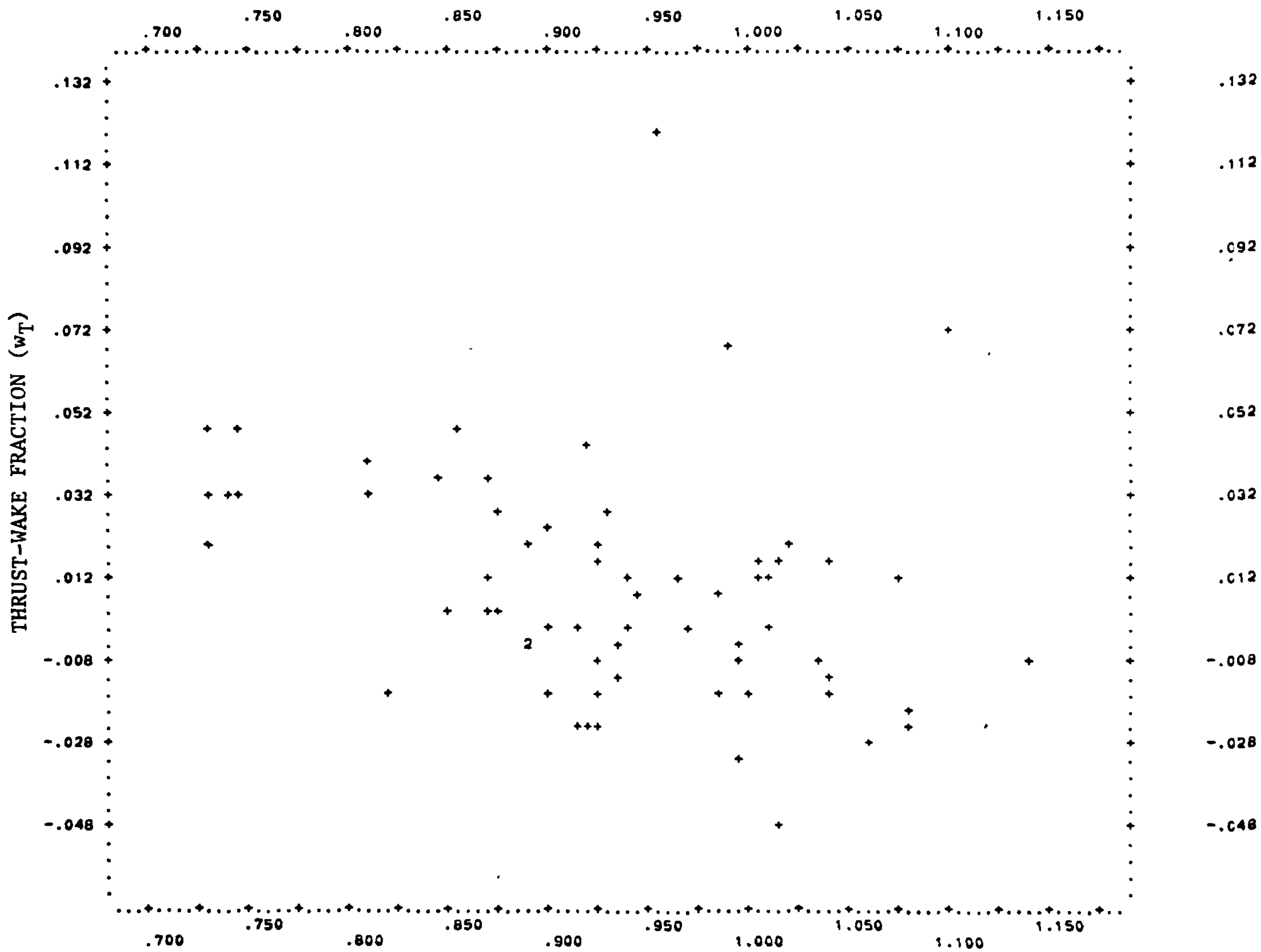


Figure D-40 - Variation of Propeller Diameter-Draft Ratio and Thrust-Wake Fraction

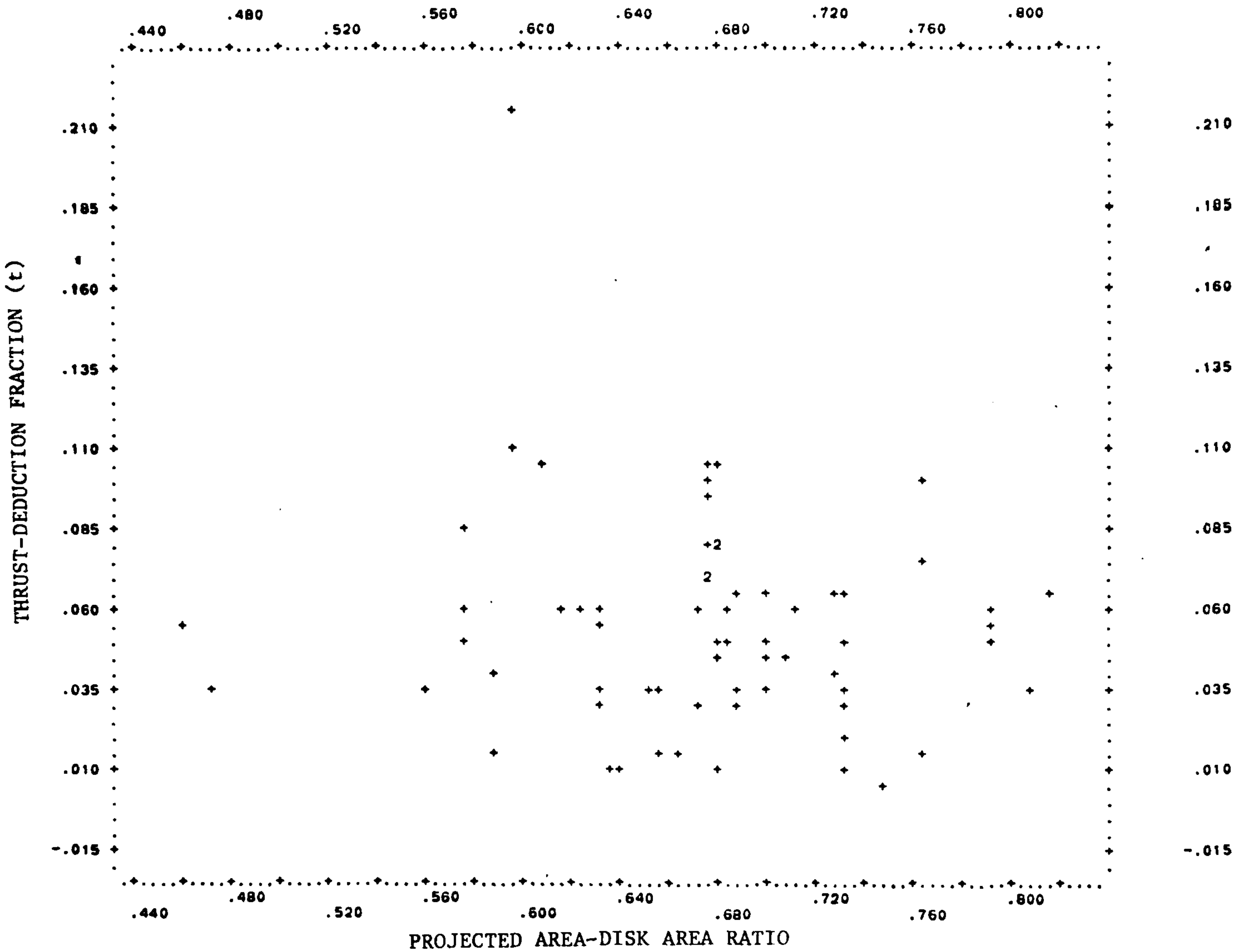


Figure D-41 - Variation of Projected Area-Disk Area Ratio and Thrust-Deduction Fraction

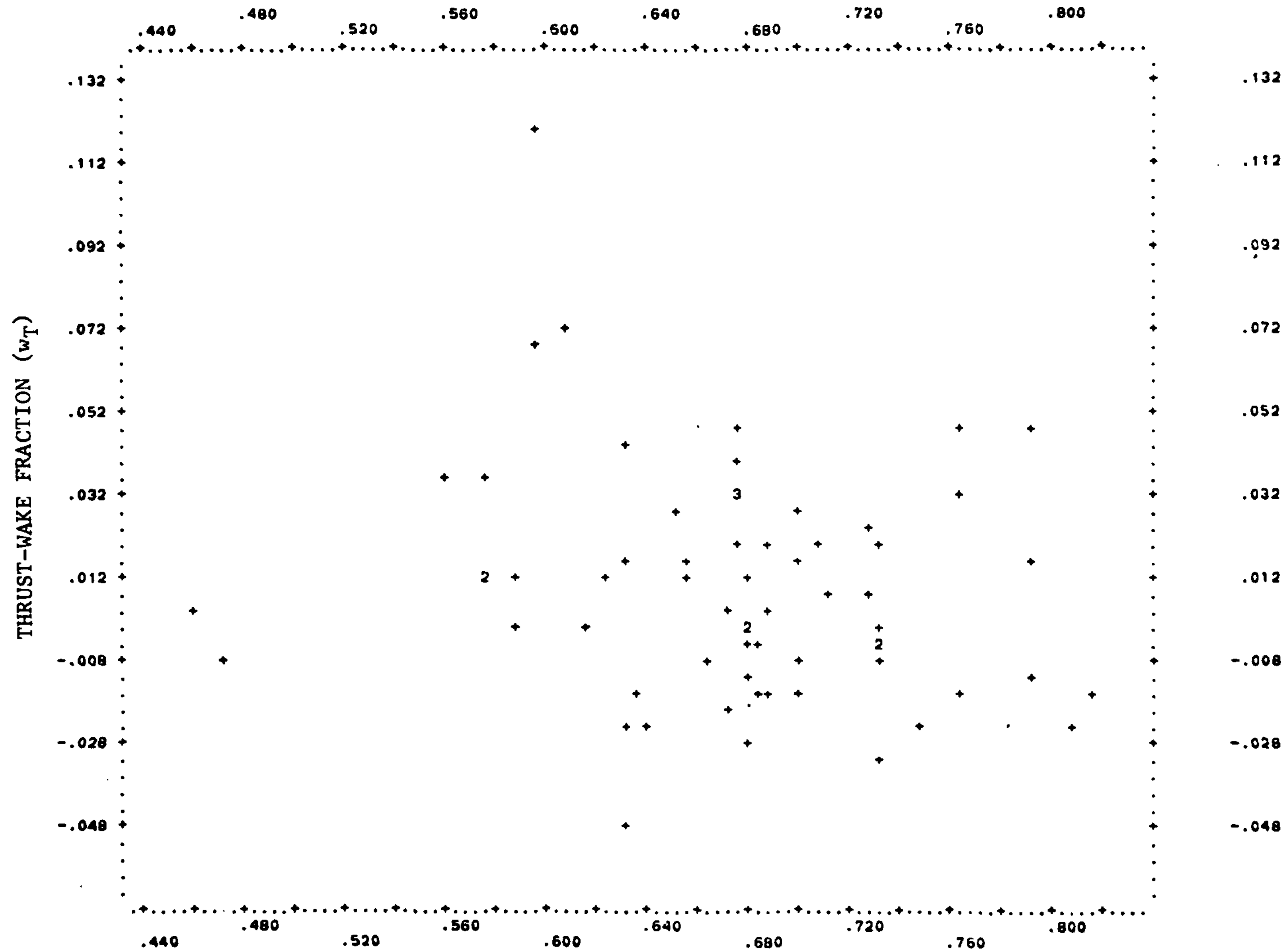


Figure D-42 - Variation of Projected Area-Disk Area Ratio and Thrust-Wake Fraction

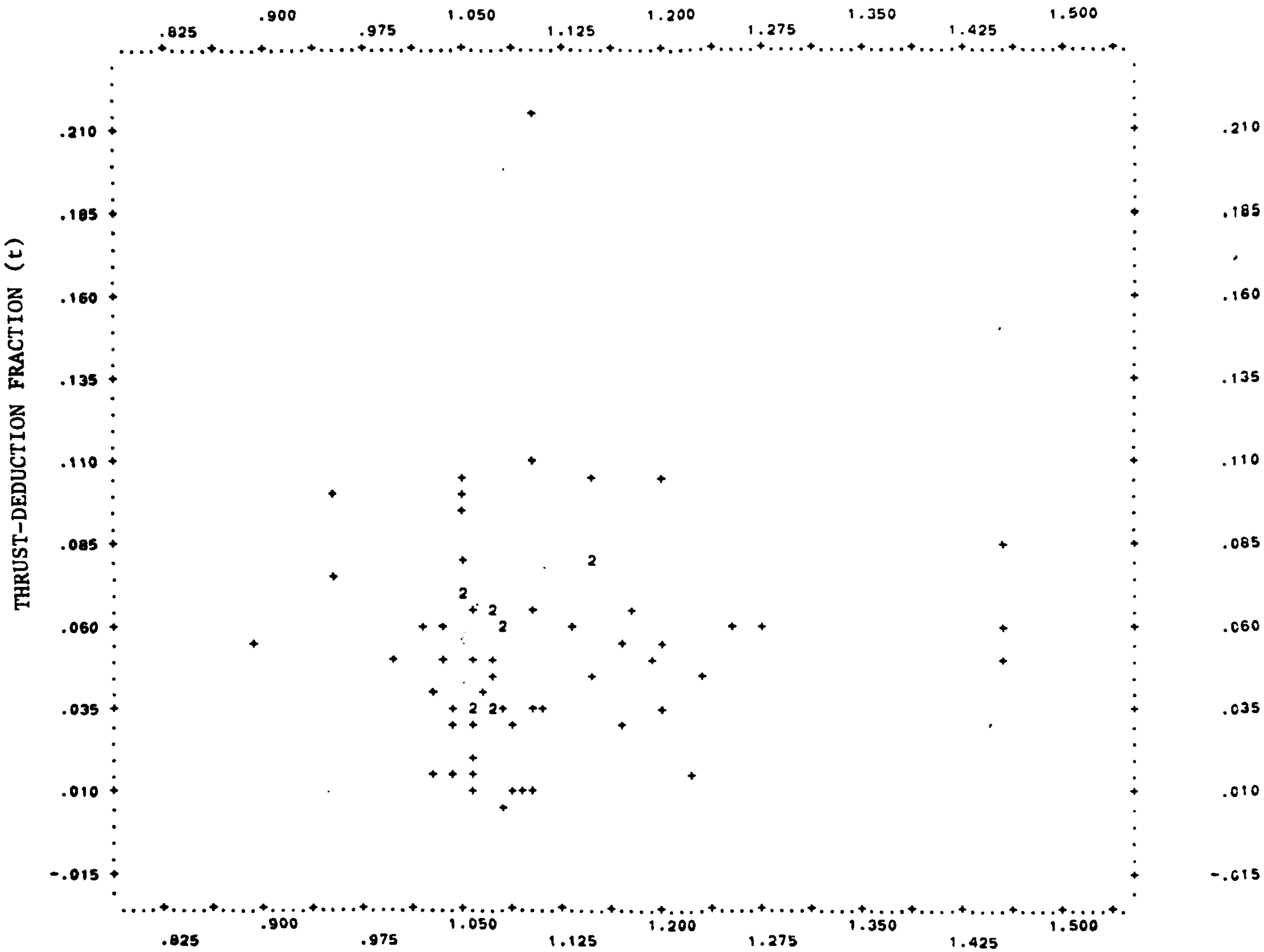


Figure D-43 - Variation of Pitch Ratio and Thrust-Deduction Fraction

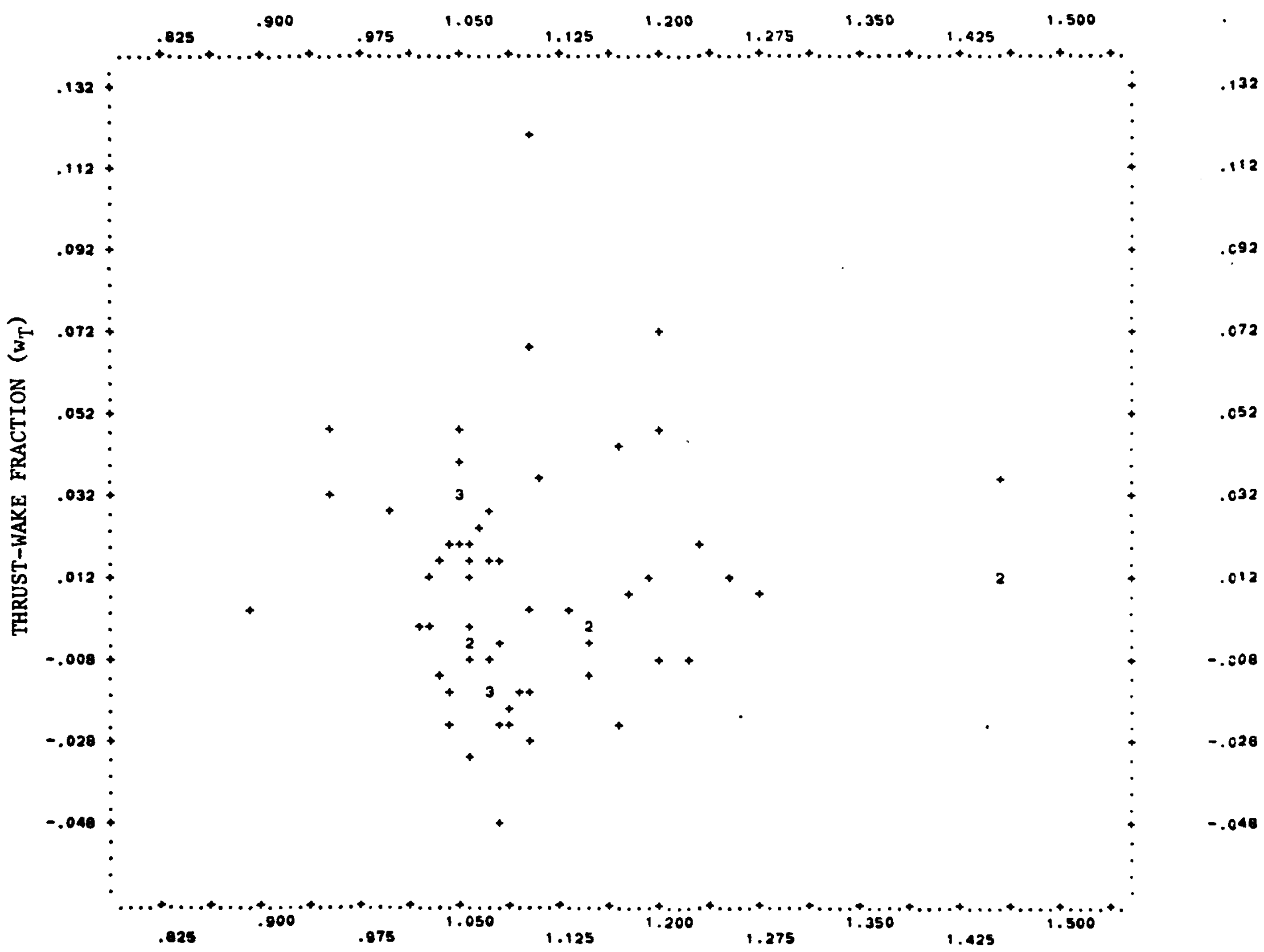


Figure D-44 - Variation of Pitch Ratio and Thrust-Wake Fraction

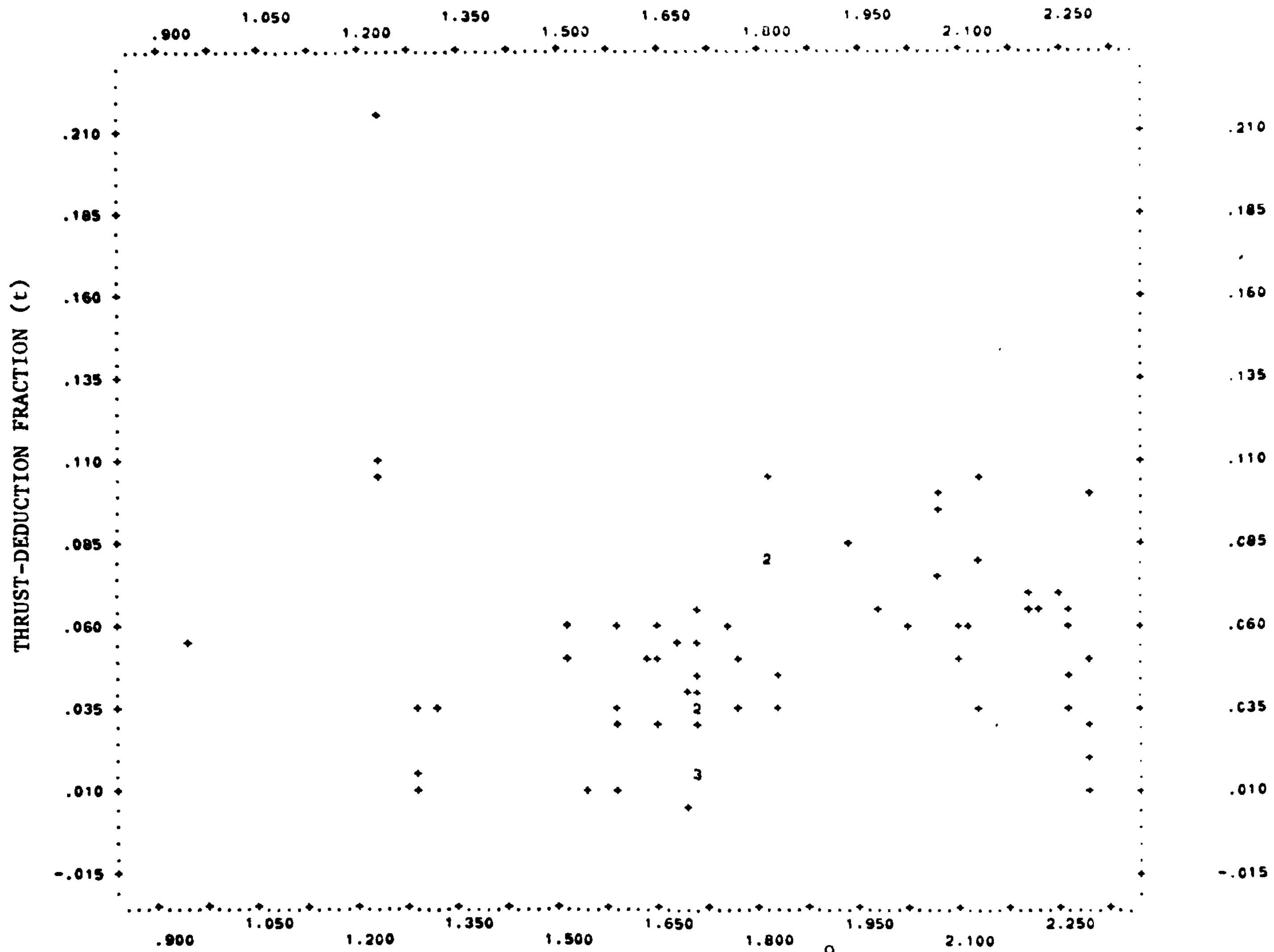


Figure D-45 - Variation of Ship Reynolds Number and Thrust-Deduction Fraction

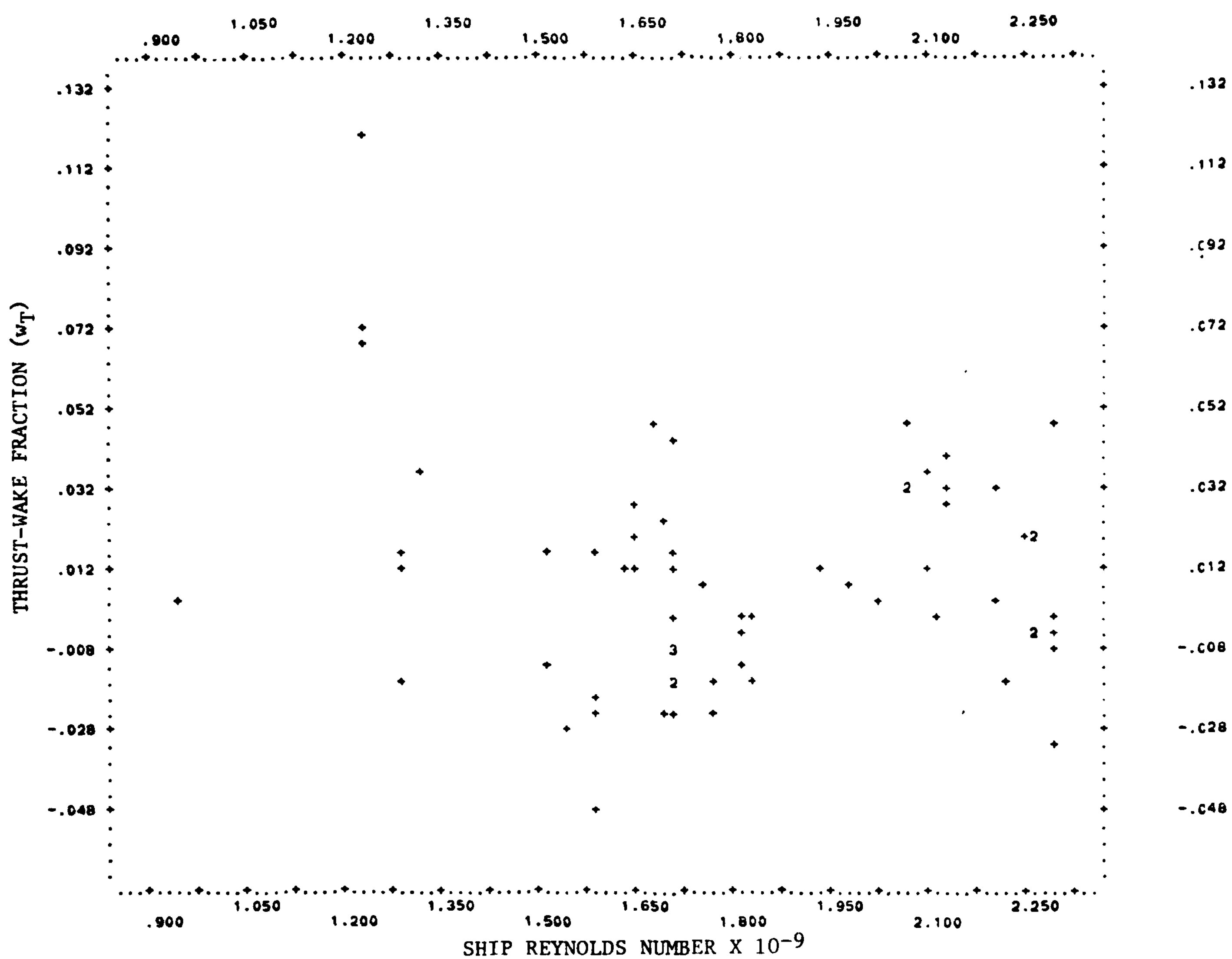


Figure D-46 - Variation of Ship Reynolds Number and Thrust-Wake Fraction

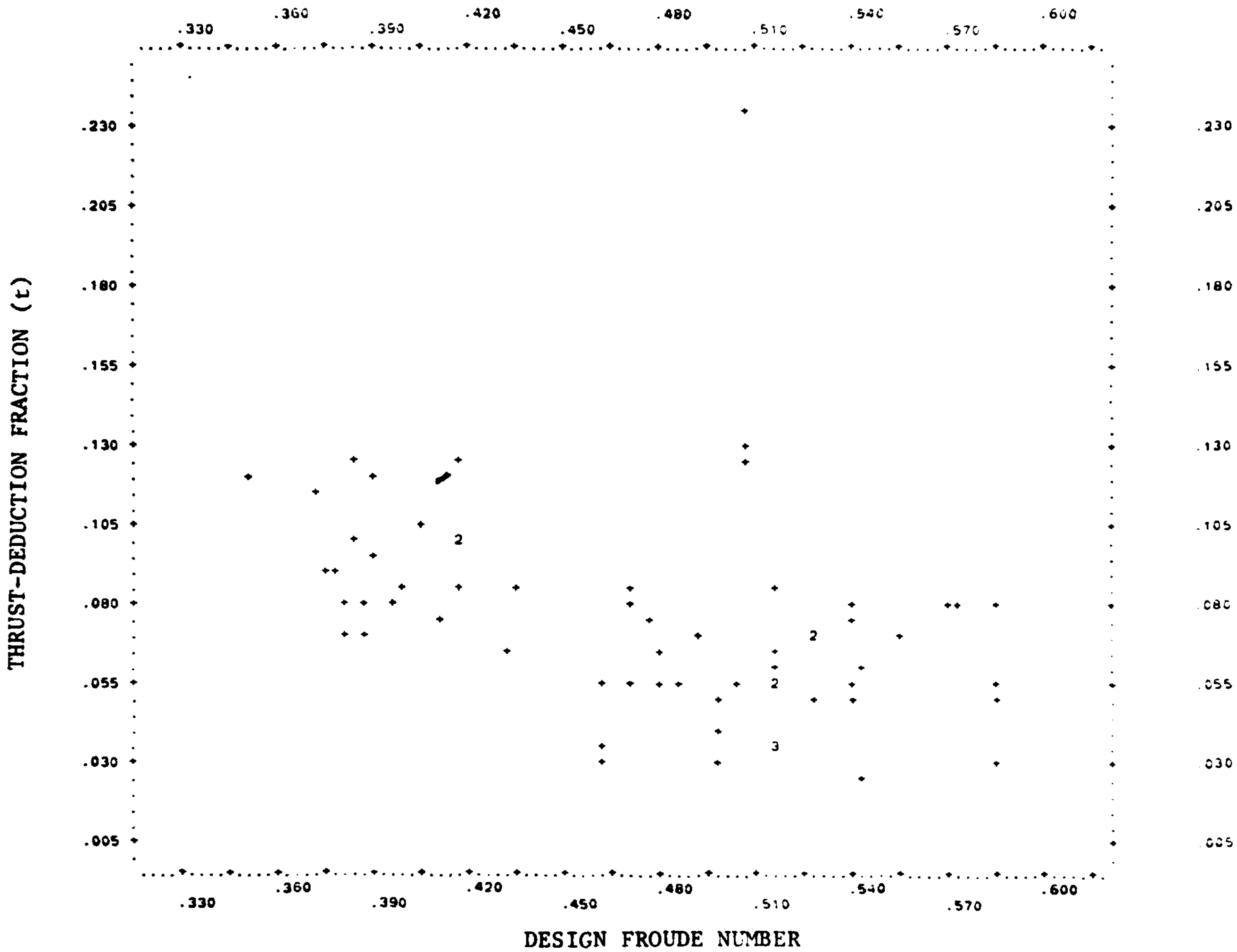


Figure D-47 - Variation of the Design Froude Number and Thrust-Deduction Fraction

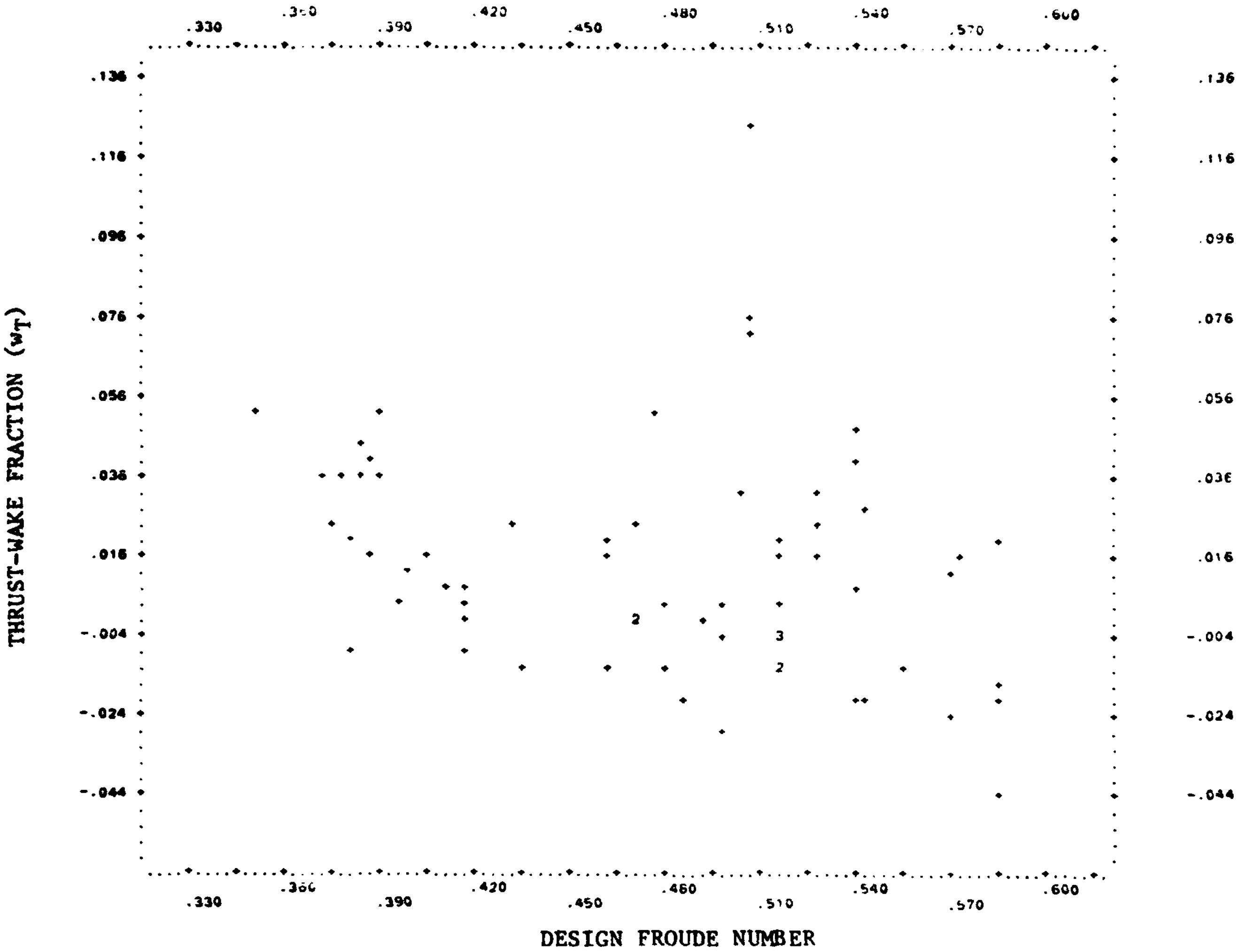


Figure D-48 - Variation of the Design Froude Number and Thrust-Wake Fraction

DTNSRDC ISSUES THREE TYPES OF REPORTS

1. DTNSRDC REPORTS, A FORMAL SERIES, CONTAIN INFORMATION OF PERMANENT TECHNICAL VALUE. THEY CARRY A CONSECUTIVE NUMERICAL IDENTIFICATION REGARDLESS OF THEIR CLASSIFICATION OR THE ORIGINATING DEPARTMENT.

2. DEPARTMENTAL REPORTS, A SEMIFORMAL SERIES, CONTAIN INFORMATION OF A PRELIMINARY, TEMPORARY, OR PROPRIETARY NATURE OR OF LIMITED INTEREST OR SIGNIFICANCE. THEY CARRY A DEPARTMENTAL ALPHANUMERICAL IDENTIFICATION.

3. TECHNICAL MEMORANDA, AN INFORMAL SERIES, CONTAIN TECHNICAL DOCUMENTATION OF LIMITED USE AND INTEREST. THEY ARE PRIMARILY WORKING PAPERS INTENDED FOR INTERNAL USE. THEY CARRY AN IDENTIFYING NUMBER WHICH INDICATES THEIR TYPE AND THE NUMERICAL CODE OF THE ORIGINATING DEPARTMENT. ANY DISTRIBUTION OUTSIDE DTNSRDC MUST BE APPROVED BY THE HEAD OF THE ORIGINATING DEPARTMENT ON A CASE-BY-CASE BASIS.

END

DATE
FILMED

1-81

DTIC